MILLIMETER ARRAY
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Millimeter Array Correlator: Further Design Details

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The correlator design for the Millimeter Array is still in a rudimentary state. It consists of the concept given in the Design Study [1], along with some refinements to the cost equation and its parameters given an a memo by me [2]. In February 1988, the Advisory Committee [3] recommended that "flexibility" be a major design goal of the correlator, with particular emphasis on being able to separate the sidebands of a DSB front end and on being able to observe more than one line at a time. This document is an attempt to consider these and other flexibility issues.

1. ASSUMPTIONS

As a starting point, consider a correlator that accepts 2 GHz of signal bandwidth from each of 40 antennas and computes the complex cross power spectrum on each baseline with a frequency resolution of 2 MHz. This is the machine whose cost we attempted to estimate in the earlier documents; let it be called the "nominal" correlator. The cost is still very uncertain, being a strong function of rapidly changing technology.

Little has been said about the organization of the signals or about the various possible modes of operation. Here we assume that:

a. The 2 GHz bandwidth is supplied in $J \geq 4$ separate channels, and these can be processed independently by the correlator. The channels may be from different front ends, from different parts of a wide IF in one front end, from different polarizations, or some combination of these.

b. Fringe stopping has been done in the LOs. This means that the fringes have been stopped at the total LO frequency for each channel or at the center frequency of the channel.

c. The front ends use double-sideband mixers, but accurate phase switching of the first LO in increments of $\pi/2$ is possible, and this can be synchronized with correlator integrations.

2. OPTIONS

Separation of Sidebands. Given the assumption that accurate phase switching of the first LO is available, visibilities in each sideband can be measured separately. If the switching interval is not too short, then this requires doubling the size of only the long term accumulator in the correlator. The long term accumulator is usually less than 10 percent of the cost of the cross-correlation part of the correlator. If the short-term dump time of the correlator is 100 msec, then for 40 antennas the total switching cycle time would be 6.4 sec (assuming Walsh function switching patterns), which becomes the quantum of integrating time for sideband-separated observations.

The sideband separation does not in itself impose any SNR penalty; that is, a line appearing in only one sideband will be detected with the same SNR whether or not the sideband separation procedure is applied. But the noise of both sidebands is present in each result, so the SNR is worse than if the front ends had been single-sideband, typically by a factor of $\sqrt{2}$.

Polarization. For polarization measurements, the nominal correlator can be re-organized to produce the necessary cross-polarized correlations provided that only half the maximum bandwidth is processed. That is, if half of the input channels are unused then the corresponding sections of the correlator can be devoted to the additional correlations. This is possible in either the FX or XF architecture. The cost lies in providing the appropriate interconnections between correlator sections; in accord with our experience in designing the VLA and VLB correlators, the incremental cost can be made negligible by careful design. On the other hand, if full polarization measurements must be made at the full bandwidth, then the cost of the *cross correlation part* of the correlator must be doubled. With present technology, it appears that the cross correlation part dominates the cost in any architecture, in which case the total cost also doubles. In the XF case, it is also possible to obtain polarization measurements by degrading the spectral resolution while continuing to process the full bandwidth. This does not work with an FX correlator.

Multiple Observing Bands or Lines. This has a bigger effect on the design of the front ends and IF processing than on the correlator. The question is to what extent the correlator input channels are separately tunable. We have assumed that a minimum of 4 channels is available, and for various reasons 8 or 16 channels may be more appropriate. It is straightforward to arrange that each channel may be tuned to any frequency within the bandwidth of the first IF; in addition, any available front end can be connected to any channel.

It may be desirable to operate different channels at different resolution or bandwidth. This will be possible if the correlator is organized as J quasi-independent correlators, each handling one channel of all N antennas. Such an organization also facilitates a future increase in J by adding identical hardware, but makes difficult a future increase in N.

High Resolution. The maximum bandwidth of each channel is B/J, where B is the total bandwidth (assumed to be 2 GHz) and J is the number of channels. If the channel bandwidth is reduced by filtering, then the resolution can be decreased by recirculation. This applies to either the FX or XF architecture, but in the FX case the additional memory must be built into every stage of the FFT engine and the number of stages must be increased by $\log_R \alpha$ where α is the bandwidth reduction factor and R is the FFT radix. In any case, the resolution becomes $b/alpha^2$. The same is true if the total bandwidth is reduced by not using some channels, keeping the bandwidth of each channel the same, provided that the cross-correlation hardware of the unused channels can be re-allocated.

The FX correlator is at a disadvantage because it must be built for a particular maximum FFT length. The VLBA correlator has a degree of freedom not available here, namely variation of the tape speed to keep the correlator input bandwidth constant while varying the observing bandwidth.

Trading Baselines for Bandwidth or Resolution. If each antenna actually provides more channels than the correlator can process, then by not using some antennas and connecting the extra channels from the remaining antennas to the now-free correlator inputs, larger bandwidth can be accepted. This would be useful only for special purposes, such as observing more lines simultaneously when SNR and (u, v) coverage on any one line is not a limitation.

Another such trade is conceivable. While retaining all antennas at the full bandwidth, some baselines might be of little interest because of redundant (u, v) coverage. In principle, the cross correlation hardware for these baselines might be re-allocated to improve the spectral resolution on the other baselines. However, this increases the complexity of correlator organization to such an extent that it should not be implemented unless a strong case is made for its importance.

References

[1] *Millimeter Array Design Concept*, section VI.4, NRAO, Jan. 1988.

[2] L. R. D'Addario, "Millimeter Array Correlator Cost Equation," MMA Memorandum No. 55, July 1989.

[3] R. L. Brown, "Millimeter Array Advisory Committee Suggestions," April 13, 1988.