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Enhancing the Performance of the Baseline ALMA Correlator

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Abstract

The performance of the baseline ALMA correlator in spectral resolution can be easily and inexpensively enhanced. The time-division architecture of the system is completely consistent with the requirements of a so-called digital hybrid correlator. By replacing the present digital filter card with one of a more complex design, the spectral resolution performance of the system could be increased by factors as high as 32.

Present Design

The present design of the baseline ALMA correlator in the widest bandwidth mode of operation (2 GHz per baseband output) breaks the high-speed input samples into 32 parallel packets, each consisting of one millisecond of contiguous samples. Each packet has a clock rate 1/32 of the original 4 GHz sample rate or 125 MHz and is cross-correlated in a separate correlator array. In wide band operation, the results from 32 correlator arrays are summed to get the final (almost) 100% efficient result.

The system has a digital filter for operation at reduced bandwidth. When working at a 1/2, 1/4, 1/8, … fraction of the maximum bandwidth, some of the 32 parallel correlator arrays required at the maximum bandwidth are available to increase, by factors of 2, 4, 8, …, the spectral resolution.

Enhancing the Design

The parallel correlator array architecture of the baseline correlator is the same architecture required by a generic digital hybrid correlator. The parallel structure could as well be used to process the frequency division outputs of a digital filter bank as the time division outputs in the current system.

The current digital filter has a simple FIR architecture with 2048 hardware tap weight multipliers. When programmed as a 1/2 band filter, it has the performance of a 2048/16 or 128 tap digital filter. When working as a 1/32 band filter, it gives full 2048 tap performance. While the filter card may be operated as a bandpass filter, present intention is that it will always be used as a lowpass filter.

A new digital filter card designed as a bank of bandpass filters, each driving some number of parallel correlator planes, would transform the baseline correlator into a performance-enhanced system. Tradeoffs could be considered in which a new filter design would consist of a variable length filter bank, each segment driving a time-division portion of the total correlator (a hybrid hybrid?). Thus, the length of the filter bank could be considered as just another parameter in the operation of the correlator to be set so as to best conform to a given observation in terms of spectral quality (number of seams in the spectrum) and spectral resolution (total number of spectral points across a band).

The table below, for a single baseband output processed in a single quadrant of the correlator, illustrates possible options for filter bank lengths of 4, 8, and 32 bandpass filters. Many other possibilities of operation with multiple quadrants, polarization, or polarization cross products are possible.

BANDWIDTH	PRESENT PERFORMANCE	4 FILTER BANK	8 FILTER BANK	32 FILTER BANK
2 GHz	256 spectral points	1024 points	2048 points	8192 points
1 GHz	512 spectral points	2048 points	4096 points	8192 points
500 MHz	1024 spectral points	4096 points	8192 points	8192 points
250 MHz	2048 spectral points	8192 points	8192 points	8192 points
125 MHz	4096 spectral points	8192 points	8192 points	8192 points
62.5 MHz	8192 spectral points	8192 points	8192 points	8192 points

As can be seen, the performance peaks at 8192 spectral points for all bandwidths which is the 256 lags per quadrant per baseline present in each correlator array times the factor of 32 parallelism in the baseline correlator. For this reason (absent a recirculator to take full advantage of a filter band at the lower bandwidths), operation at lower bandwidths with many filters in the filter band would probably not be very useful.

In the widest bandwidth/highest resolution mode, 2 GHz spectrum processed in each quadrant of the correlator with 32 filters, the spectral resolution would be 244 kHz for a single polarization, 488 kHz for two polarizations, and 977 kHz with full cross-polarization products.

Operation of the correlator with a filter bank 32-filters-wide in any mode might not be feasible because it would require 32 very sharp digital filters and be difficult to fit into the present filter card form factor. Advanced techniques, such as poly-phase filters, however, might allow such high-resolution operation with acceptable results.

Changes Required

The changes to the present baseline ALMA correlator required to realize this performance enhancement are rather simple. A new and much higher performance digital filter card design is required. Any new high-performance design will probably require a latest-generation FPGA (field programmable gate array) family which implies a FPGA core voltage not presently distributed in the correlator station hardware. The new voltage could be supplied by DC-to-DC converters on the new filter design but would probably be best supplied by a new bin power card. A modification to the bin motherboard to distribute the new voltage would also be required.

Both the power card and motherboard modifications would require minimal effort. The present power card already has provisions for an additional voltage, and the motherboards are designed to be easily replaceable.

The usefulness of any performance increase in the baseline correlator will be restricted by the present specification of the total output data rate of the correlator (about 1 Gbyte/sec). Any increase in this rate would have many implications on the correlator itself and on the output computer system.

Software issues will, of course, also be present.

Cost Estimate for the Change

A lot of study will have to be made to ascertain the optimal performance required from the new filter card design. Once a target performance is decided upon, implementation issues, such as selecting a FPGA family or possible custom ASIC design, will be studied before a detailed logic design can be made. Total cost of the new filter, while very uncertain at this time, will probably be within a factor of 2 of the present filter. Present cost estimate for the filter cards for all four quadrants is about $0.5 million. The cost of new power cards and new station motherboards would be small compared to this.

The total cost of this correlator enhancement also depends on when it is implemented. The change could come with the first quadrant delivered to the site, but the new filter card development might cause a delay in the delivery. A more costly approach would be to have the new filter come with the last three quadrants and retrofit the first quadrant.