Distributed Correlator for Space Applications

A.W. Gunst*, L. B. Venema, and A. Bos

ASTRON Netherlands Foundation for Research in Astronomy, Dwingeloo, the Netherlands

* Contact: gunst@astron.nl, phone +31-521-59 5113

***Abstract*— Earthbound radio telescopes use for the processing of the received signals a central correlator system. However, for interferometry in space using free flying units, where downlink bandwidth, the power dissipation and space per satellite is limited, a distributed correlator can be more advantageous. This distribution reduces the risk of failures as well.**

In this paper the proposed architecture for a distributed correlator in space is discussed.

I. Introduction

In radio astronomy interferometers are used to enhance the sensitivity and angular resolution for observations. Recently [1] an initiative was started to use interferometers in space for the submm regime. In space different requirements for the correlator apply. In this paper a correlator architecture is proposed for interferometry in space.

As a starting point the block diagram of a traditional telescope system is presented in Section II. From there on the requirements for a correlator in space, distributed over multiple satellites is discussed including a block diagram. The distributed correlator is more detailed in Section IV. The impact of a failing satellite is discussed in Section V.

II. A Ground Based Receiver System

The incoming radiation is measured using one or pairs of orthogonal dipoles in the focal plane of a dish. In the low frequency range this is often limited to just a large number of dipoles [2].

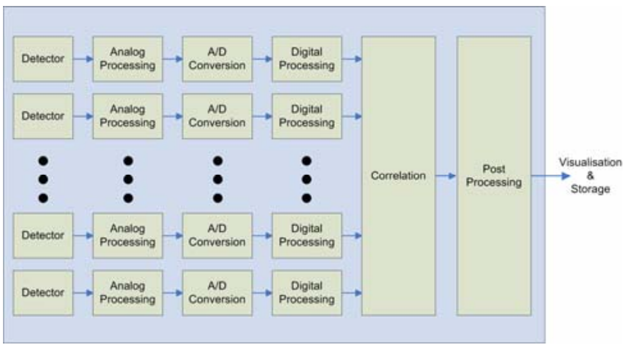

Figure 5 Block diagram of a ground based receiver system

The dipole signals are amplified, filtered and mixed down to baseband. The signal processing that follows involves generally down conversion to baseband, analog-to-digital (A/D) conversion, fringe- and delay tracking. Fringe tracking is often combined with the down conversion in the analog block. The number of bits to be used for A/D conversion is determined by the characteristics of the input signal, the required dynamic range and the loss in sensitivity allowed. Delay tracking is preferably done in the digital processing block. The digital signals from each antenna are send to a central correlator. The correlator computes the cross-correlation between all possible antenna pairs. This reduces the output data rate of the system by orders of magnitude. The WSRT correlator for example reduces its input data rate of 40 Gbits/sec to a maximum output data rate of 30 Mbits/sec.

After the correlation process the correlator products are e.g. calibrated, flagged, etc. in the post processing block. Finally the result is used to generate images.

III. Correlator Requirements in Space

The system concept consists of a number of satellites equipped with an antenna and a receiver system. This is depicted in Figure 6. The satellites are free flying. In this way the baselines in between the satellites can be varied as function of time, delivering an acceptable UV coverage even with a small amount of satellites.

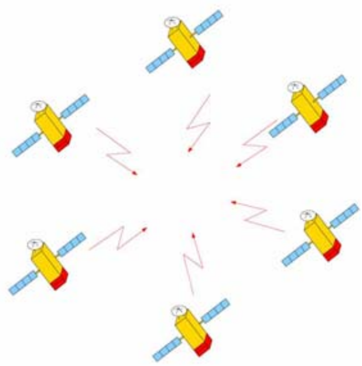

Figure 6 Satellite configuration for an interferometer in space

Observations in the submillimeter wave length range require a typical receiver bandwith in the 1-10 GHz range. The bandwidth available for the downlink will be insufficient to cope with the required data rates.

Since, the correlation process reduces the data significantly it is more efficient to implement the correlator in space as well. One of the consequences is that a communication is necessary between all satellites as is depicted in Figure 6.

Driven by risk reduction and the need to balance the power load over all satellites and to benefit from series production to have only one type of satellite it is desired to share the correlator over all satellites. Furthermore, the communication bandwidth in between the satellites should be minimized.

These requirements results in the block diagram as shown in Figure 7. The first blocks in Figure 7 are common with ground based telescopes, except the correlator block which is now distributed. Furthermore, the post processing can be done on earth because the amount of data in the correlator is reduced significantly to downlink this. An example of data rates is presented in [4].

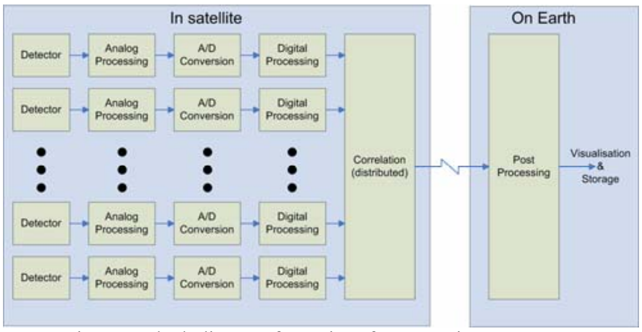

Figure 7 Block diagram for an interferometer in space

IV. Distributed Correlator

In principle there exists several ways to distribute the correlator functionality over the satellites. Amongst them are: distribution in antennas, time and basebands/subbands.

The correlator can be distributed over antennas, by calculating a subset of cross correlation products in each satellite. The correlation process can also be distributed in time, so that satellite 1 correlates the first time slot, satellite 2 the second time slot, … and satellite N the N^{th} time slot. The next time slot $N+1$ is again correlated by the first satellite. Finally, distribution in frequency can be done by splitting the frequency band up in N parts, where each satellite correlates its own frequency band.

In [3] all three concepts are compared. The communication data rate in between the satellites is minimized by adopting a distribution in time or basebands/subbands. For a correlator distributed in time extra buffer capacity is required. Furthermore, the number of correlator multipliers in a frequency distributed correlator is less. Hence, a distribution in frequency is proposed.

Many radio telescopes use an XF correlator, meaning that first the correlation and integration of the signals is done in time domain (X), after which the Fourier transform (F) is accomplished to get a cross power spectrum out of the correlator. This is an economically attractive technique for radio telescopes with a limited number of detectors. The number of multipliers required for an XF correlator equals

$$\frac{N \cdot (N+1)}{N} \cdot N_S$$

wherein N is the number of satellites and N_S is the total number of spectral channels. All multipliers in an XF correlator run at the input clock frequency f_s.

For systems with a large number of antennas it is more economical to use an FX architecture. A number of existing systems use a combination of the two architectures, the hybrid architecture (HXF).

In an FX architecture the input band is split in frequency such that the required spectral resolution after correlation is met, while in a HXF architecture the input band is split into basebands/subbands first. An XF correlator per baseband/subband is used to produce the final spectral resolution.

Both the FX and HXF correlator are a usefull architecture for a distributed correlator, since both splits up the band prior to correlation. The choice between both depends on detailed parameters like flexibility, power consumption, etc.

Also for a FX and HXF correlator the number of multipliers required for the correlation equals the number of spectral channels. However, the multipliers can run on a decimated clock rate, dependent on the baseband/subband width. If the filtering operation is implemented digitally, then also multipliers for this operation are required. The exact number depends on the required ripple, stopband attenuation and transistion region of the filter. Furthermore, in the FX architecture also the multipliers for the FFT should be counted.

Assuming a HXF architecture, then the number of correlator multipliers for a 1 GHz band sampled at $f_s = 2$ GHz is depicted in Figure 8 assuming 512 spectral channels. The band is split in four basebands with analog filters and the number of multipliers equals the number of spectral channels N_s. While in a XF correlator all multipliers are running at the input clock frequency of f_s, the multipliers in the HXF correlator run at the downsampled rate of f_s /4 in this case. This saves chip area or power consumption.

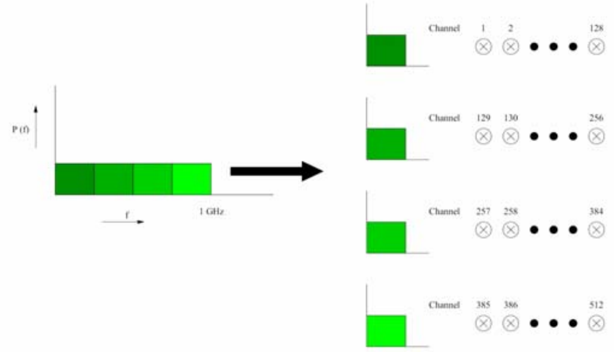

Figure 8 Number of correlator multipliers for a HXF correlator

With the proposed solution all satellites can be identical. Given *N* satellites each satellite processes 1/*N* of the total input bandwidth. Satellite *i* correlates band *i*, where *i*=1 … *N*. This means that all satellites have to transport their digitized signal in band *i* to satellite *i*. So, in this case satellite 1 transports band 2 to *N* to satellites 2 to *N*, while it receives band 1 from all the other satellites.

V. Satellite Failure

The proposed architecture is robust for satellite failures. When one of the *N* satellites fails, one detector fails and part of the correlator fails. That means that part of the bandwidth cannot be correlated anymore by the failed satellite. As a consequence the processing in the other satellites is more relaxed since the number of detectors to correlate is reduced by one. This extra capacity can be used to correlate the original bandwidth again. Even then processing power is left over because the number of multipliers required for the correlation relates quadratically with the number of detectors and linearly with the bandwidth.

Conclusions

In this paper a distributed correlator is proposed for interferometers in space. For a distribution in the frequency domain, a power efficient and robust solution is found. The internal data rates in between satellites are optimised in this configuration. Finally all satellites can be identical and no single point of failure is present in the proposed solution.

References

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