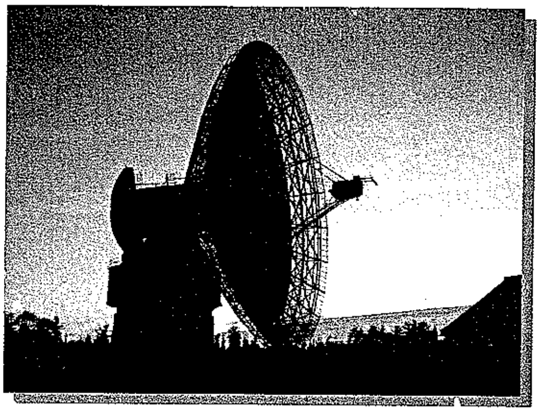
International VLBI Service for Geodesy and Astrometry

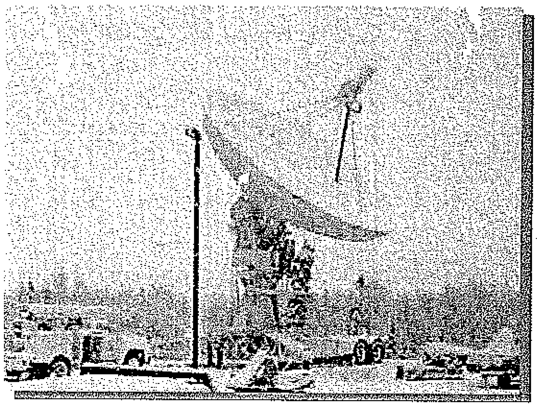
2004 GENERAL MEETING PROCEEDINGS

Ottawa, Canada

February 9-11



IVS 3rd GENERAL MEETING 2004 Ottawa, Canada • February 9-11



NASA/CP-2004-212255

Backend Systems – Perspectives in 2010

Gino Tuccari [1], *Alan Whitney* [2], *Hans Hinteregger* [2], *Yasuhiro Koyama* [3], *Tetsuro Kondo* [3]

[1] *INAF-IRA, Italian National Astrophysical Institute-RadioAstronomy Institute*
[2] *MIT Haystack Observatory*
[3] *CRL, Communications Research Laboratories*
Contact author: Gino Tuccari, e-mail: g.tuccari@ira.cnr.it

Abstract

A new technological vision on the future of the VLBI backend area let envision a fully digital implementation of what was until now performed in the analog domain. Several advantages can indeed be expected moving the domains transition point in an earlier stage, at IF frequency instead than at the final base-band. Such quantum leap can be afforded because of the rapid changes in digital technology that radio observatories continue to look for maintaining their competitive edge. New processing technologies here discussed will make it possible to reconfigure the whole data handling process using digital conversion to base-band and then to fully benefit of the high data rates in new acquisition and data transport systems, while simultaneously improving the reliability and flexibility of the signal path. In addition, a digital representation of the IF and base-band signals will provide the opportunity to correct for various RFI and calibration effects using embedded DSP algorithms. In order to implement these new techniques a number of major modifications are needed at all telescopes for both single-dish and for VLBI operations. Such modifications could greatly enhance the overall sensitivity of the observatories and improve the reliability of operations. The new hardware should comply with the internationally adopted standards for VLBI in order to allow global applications. A further final step we could anticipate is a brief look at a 'next' future, after this near future: a trend to move yet the transition point closer to the sky frequency, overlapping with the receiver area.

1. Introduction

Since the VLBI introduction in the radioastronomy community it was evident a deep fusion of the interferometric methodology with the technological solution to implement it. Whether this was pertaining the receiver area with the introduction of the great deal in the phase stability of the constituting components and particularly with the frequency conversions performed with the best achievable phase lock conditions, the actual complication in the equipment area was related to the back-end instrumentation. Indeed, still maintaining a fundamental need to keep the received signals with a great phase stability all over the process, this section presented the place where the interfacing between receivers and recording media was placed, with all the limitations and compromises this could show.

The evolution up to the present times is then bringing us with an aspect coming from the historical adaptation dictated by the best possible solutions at the time. In particular the limited width in the recorded band with respect to the entire available, and potentially usable, so as the technological limitation in the maximum working frequency in the correlation components, imposed the important architecture development of our present backend systems.
Any new technology now available that could improve the performance and simplify the data process has to be taken into account, and a new perspective should be envisioned to be operative in

the near future we are taking into consideration, for the end of the present decade.
Such process is of great importance not only for the opportunity now introduced by the network connections and new recording systems, but even because a further step could be considered: not only improvement and adaptation of new technology with the traditional method, a necessary step to guarantee the continuity, but even a more radical approach whose the VLBI data processing could benefit. Such consideration, on the other hand could contribute to address other areas, correlators, receivers, data transfer, to converge up to solutions of excellence. This description is only a preliminary and limited collection of considerations we think useful in such direction, and for sure more discussions are necessary for achieving a well delineated vision. It could hopefully represent a starting point for discussion.

2. Performance of a VLBI backend in 2010

A system able to replace a present VLBI terminal would as minimum perform the same functionality and doing the same in a fully digital fashion would immediately represent several advantages. Reproducibility and phase stability are the main elements involved in such scenario: any terminal would be exactly the same with respect to any other, clock stability would be guarantee for the quality in terms of phase stability. A digital version then would represent an obvious goal.

Let's consider a list of element included in the traditional acquisition terminal and for each element consider the equivalent functionality in a digital system for each 400 MHz width IF an analog backend have:
IF distributor, including total power measurement system;
A number of 8-16 baseband converters, each including functionality for tuning and single side band converting with 10 KHz step in a range from 100 to 500 MHz, or 500 - 900 MHz. Side bands wide in frequency from 0.625, 0.125, 0.25, 0.5, 1, 2 , 4, 8, 16 MHz. Automatic gain control. Total power measurements in both lower and upper side band;
Samplers at 1 or 2 bits;
Formatter or VSI-H interface.

In the same circumstances a digital backend needs to have:
No IF distributor because the first operation to perform, by definition, is the analog to digital conversion. Data distribution of the sampled signal is realized through a dedicated serial gigabit transmission system or through a parallel high speed bus. Total power measurement is needed;
Frequency conversion can be conceived in more ways, with different architectures, whose choice is deeply affecting the final features and degree of freedom. In particular we could divide in methods where the single converted channel is independent on the others in terms of bandwidth and zero converted frequency, and methods where channels are equally spaced and wide. Channel bandwidth can be greatly improved because the lack of limitation typical of the on tape writing. Total power measurement is needed in each channel;
Signals for operating in digital need to have a wider representation with respect to the 1 or 2 bits, and this appears more evident whether a control in the RFI area needs to be included.
VSI-H is a standard interface between instrumentation, path or any other item needing a rigorous control on the timing of the data transfer. The traditional formatter is limited in the maximum

data rate for future needs, because developed for feeding a tape recorder.

Numerous improvements are then possible, taking advantage by the very different method in implementing the needed functionalities.
A first question we could ask is what could be the proper number of IFs to treat in a new back-end system. Whether a minimum number is pretty obvious, just to reflect what is today in use, a maximum is instead not so evident. Multi-frequency observations are indeed an interesting option and interleaving more than putting in parallel more frequency bands could represent an interesting solutions for several purposes in radioastronomy.
A perspective analysis regarding the geodetic VLBI has anyway to take into consideration the needs for the astronomy, because technological developments ran, up our times, together. A possible solution for giving an answer about the number of IFs a backend should support, is just to present a modular approach, where more channels could be added, considering the scientific problem to treat and a common output set of channels where data coming from more sources (frequency bands and/or polarizations) could be placed to go on the further recording media, or data transfer.

Let's consider now the bandwidth for a single IF. Numerous developments are in course in the radioastronomy community (ALMA; SKA, e-VLBI, etc.) and several analysis have been performed to choose the most proper A/D converter, considering of course the total bandwidth to process. This because different commercial options are in the field to convert with a proper number of representation bits, the received signals. Excellent low cost solutions are possible even if the major bottleneck is represented by the further processing hardware elements. So is not difficult to find solutions ranging between 500 MS/s up to 1500 MS/s or even more for 500/1000 MHz slices of band.
A trade-off between bandwidth in use with the traditional VLBI receivers and hardware processing method and components capability is necessary to properly set the analog to digital conversion data rate and it appear promising to set such value not too far from 1000 MS/s, for a limitation in the cost .
Let's now evaluate what is needed as channel bandwidth coming out by our new hypothetical backend. It looks useful to have available the common channel width we are used, 1-2-4-8-16 MHz, while we could ask whether the narrower bandwidth are needed. The possibility to increase the channel to 32, 64, 128, 256, or the entire 512 MHz is worth to be taken into consideration, due to the greatly improved recording data rate. So if a trend to increase channel size in frequency looks promising, the necessity to include narrow band channelization should be carefully taken in to consideration for limiting development complexity.

The process to produce a single frequency channel, wide or narrow band, can be realized with different methods.
Some authors reported about methods making use of FFT modules, dividing the frequency spectrum in more bands, equally spaced, with channel size depending on the FFT dimension. Such modules are feed by poly-phase digital filters in order to reduce data rate and perform a filtering process.
A different method treats a channel as single unity giving the possibility to independently tune different channels choosing their bandwidth. This is reflected in a more complex implementation, but more flexible.

A crucial element that should be considered for a future backend architecture to adopt is just leaving the possibility to explore different solutions for different observing schemes, adding to the already cited modular aspect, a programmability aspect. Then it would be worth to consider in the future backend a defined architecture with functionally defined modules, implementing inside different methods or technologies, well adapted to the general or particular need to satisfy. A flexible approach can be reflected in the possibility to have tunable or fixed multi-channel modules, to have high data rate transfer modules (ex. 10G technology) or direct bus connections, and so on. A precise relation between different parts should anyway considered to guarantee an electrical and maximum data rate compatibility. Total power measurements should be included in the digital domain so as a selectable automatic gain control.

A new approach is still possible considering to add in the backend section the functionality to treat delay and fringe rotation control under a station based approach. This, while can present restrictions for astronomical usage due to the limitation in the field of view, in the geodetic data process could bring great simplification in the correlation process opening yet the possibility to easily share the process in a software approach. On the other hand a more heavy process would be left for the backend side, where a-priori calculation would be needed, with no possibility to recover for calculation errors. An deeper evaluation seems to be worth to be considered.

3. On the opportunity to move some functionalities in different sites.

Taking in consideration with a new vision, as we are trying to do, a VLBI backend functionality, it appears possible in principle to move some processes in different places, instead to maintain all together as we are at present used to see. It looks interesting to discuss about this possibility.

The conversion of the analog IF coming from the receiver is the first stage of the backend process, while being any other further activity performed in the digital domain. So it would be worth to ask whether it could be convenient to physically place the converter in the receiver area and then to transfer sampled data, using high data rate serial technology, as it could be represented by the 10G one. Indeed if data representation is 7-8 bit wide with a rate of about 1 GS/s, such standard technology could be adopted to transfer data inside an observatory or more in general inside the digital backend 'area'. Some indications could suggest useful such opportunity, because it could contribute to avoid frequency dependant performance in the traditional analog cable signal transfer, and it could represent a valid method to minimize cross-talk or interference introduction in the signal path. Still more important, signal injection for phase calibration could be much simplified, due to the single analog to digital conversion point. A great deal would still be given to the reference clock distribution. As drawback a digital front-end in the receivers area could represent a potential source of noise, so that particular care should be taken in the shielding realization.

To talk about backend 'area' is in our intention pretty valuable, because introducing a standard method to distribute high data rate signals, implies the possibility to further process the observed data even in different places. So that it could be taken into consideration a radio interference mitigation algorithm, as it was suggested by groups working in such area, adopting a real time cancellation or a more simple digital band filtering. And such process could be realized in a different place, where interference are detected and selected, as a RFI station could represent.

The data transfer technology is quickly growing so that a possibility could also be considered to fully record a received band to process later at the correlator side for tuning or bandwidth selecting. What is traditionally performed in a station could be transferred in some valuable occasions to the correlator, reducing failure risks in the station. With an almost ideal no limitation in data transfer, it would not make any sense to select portion of bands in the stations, while leaving the correlator site free to handle the data in a unique common process for all the stations. Unexpected RFI could be removed simply tuning all the station at a different band portion. This approach could appear the opposite of creating a delay and fringe rotation station based in the backend, but it is not, because simply this solution could be adopted with the backend terminal placed at the correlator side, and the delay-phase control performed in such terminal. All these solutions should be evaluated including the problems related to the sampling jitter and the consequences on placing sampling process close to the data conversion, considering the reference clock distribution.

4. Moving towards a sky frequency processing

Already now very fast A/D converters are commercially available, in excess of 20GS/s, so that it could be taken into account the possibility to sample data at sky frequency for the bands at present adopted or even for those higher if the trend will be to increase the frequency of the observed band. As soon as faster digital processing components will come to the market, able to 'fill' a VLBI network with sampled data, still a much simpler, and faster, process will be adopted, greatly simplifying the backend role, up to its minimization and integration with the correlator.