Atacama
Large
Millimeter
Array

ALMA 2GC System Requirements

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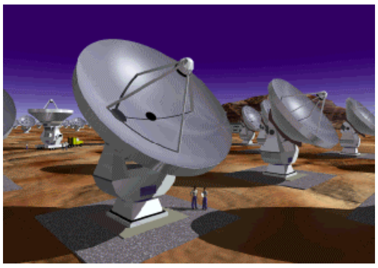

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1 Introduction

The Atacama Large Millimeter Array (ALMA) is a next generation radio telescope operating in the mm/sub-mm wavelength window. Compared with present day telescopes, ALMA will provide higher sensitivity and higher spatial resolution over a wider bandwidth. Since, there are many astronomical applications for ALMA [1] the instrument must be versatile and flexible in order to satisfy a broad range of observing modes.

The first generation correlator (Baseline Correlator) designed and currently under construction by the National Radio Astronomy Observatory (NRAO) is a traditional XF correlator incorporating many channels and digital filtering. In parallel, the European team has started the design of a second-generation correlator (2GC) for ALMA to enhance the observational possibilities and sensitivity using the latest technology and new design ideas. The 2GC is based on a hybrid architecture design (intermediate between the XF and FX designs), whose main characteristics have progressively emerged from the European Phase 1 study. The possibilities of the European design and its straw-man schedule have been briefly presented in [1], Chapter 10. Details of the 2GC architecture are given in [2]. Compared to the baseline correlator the 2GC will provide higher sensitivity and spectral resolution, and a very flexible use of the ALMA resources.

This document presents the system requirements for the design of the 2GC; they are derived from the guidelines for the 2GC specifications issued by the ALMA Scientific Advisory Committee (ASAC) [3]. In Section 2 the 2GC is defined and the top level requirements are discussed. The top level interface requirements are covered in Section 3.

2 Top Level Requirements

After the 2GC system is defined and the top level technical requirements are given we list and briefly discuss the top level assumptions. The 2GC top level requirements are distinct from the engineering specifications. A change in the top level requirements may affect the scientific goals of the ALMA 2GC and thus concerns scientific users.

2.1 System Boundary

In Figure 1 a sketchy overview of the ALMA system is given, showing only the data path. The system boundaries of the 2GC are indicated.

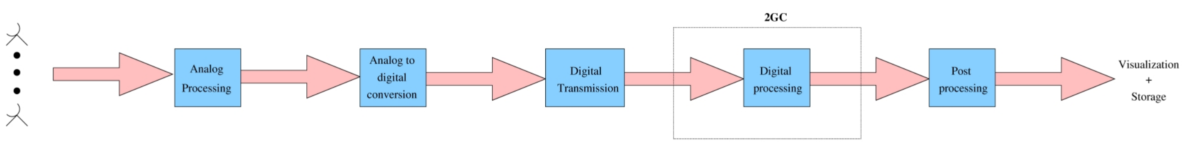

Figure 1 Overview of the ALMA system.

The data path of the 2GC system is detailed further in Figure 2. Connections with the control system and references are not indicated. This will be further detailed in a separate design document, describing the proposed architecture and interface definitions. Our goal in the implementation of the 2GC design is to use as much of the infrastructure and features of the current design as possible. The interfaces between the 2GC and the current system are specified in Section˚3.

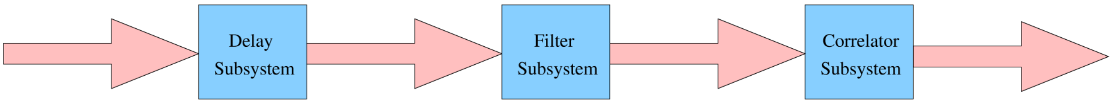

Figure 2 Overview of the 2GC system.

2.2 Technical Requirements

A general architecture has to fulfill the currently known requirements, but also has to add extra features, which may turn out to be useful later on. The goal is to cope, within reasonable boundaries, with evolving observing modes and strategies suggested by the scientific users. Therefore the 2GC has to offer high flexibility to exchange the number of basebands[1], subbands[2] within a baseband and antennas against spectral resolution. The 2GC flexibility is embedded mainly in the correlator and filter subsystems architecture. Different Finite Impulse Response (FIR) filter architectures are discussed in [5], the 2-stage filter solution adopted at this time is described in [6] and practical implementation in various families of FPGAs is ongoing.

In the 2GC system the subbands are tunable within a baseband. To meet the resolution requirements for narrow band spectral line observations it is required to have a selectable subband bandwidth in combination with re-circulation. Reducing the subband bandwidth with a maximum factor of 8 allows us to position all filters in a single baseband and to use a maximum re-circulation factor of 8.

A short list of typical examples of the 2GC capabilities is listed in Table 1. The widest band continuum observations are represented in the first three rows (indicated by a light color). In this table the subband width of each subband is assumed to be the same. In the 2GC design it is required to have independent filters. Hence, an astronomer will observe some spectral windows with higher resolution than others. Furthermore, baseband switching allows the astronomer to observe a given spectrum with different resolutions, thus enabling to zoom a specific spectral region. By setting the center frequency of multiple subband filters at the same position and selecting different subband widths, zooming can be established for each baseband independently as well.

[1] A baseband is an input band of 2 GHz. The total number of basebands is 8 or 4 pairs. The two basebands of each pair have the same frequency but different polarizations.
[2] A subband is a part of a baseband. All basebands are split into subbands by the digital filter subsystem.

								Including re-circulation		
Number of				Subband width	Total baseband width	Spectral channels	Spectral resolution	Re-circulation	Spectral channels	Spectral resolution
ntennas	basebands	polarization products	subbands	(kHz)	(MHz)	per subband	(kHz)	factor	per subband	(kHz)
80	8	4	32	62500	8000	32	1953,125	1		
80	8	2	32	62500	8000	64	976,563	1		
80	4	1	32	62500	8000	128	488,281	1		
80	4	4	32	62500	4000	64	976,563	1		
80	2	4	32	62500	2000	128	488,281	1		
80	8	2	16	62500	4000	128	488,281	1		
80	8	2	8	62500	2000	256	244,141	1		
80	8	2	4	62500	1000	512	122,070	1		
80	8	2	2	62500	500	1024	61,035	1		
80	8	2	1	62500	250	2048	30,518	1		
80	8	2	32	31250	4000	64	488,281	2	128	244,141
80	8	2	32	15625	2000	64	244,141	4	256	61,035
80	8	2	32	7813	1000	64	122,070	8	512	15,259
80	8	2	16	7813	500	128	61,035	8	1024	7,629
80	8	2	8	7813	250	256	30,518	8	2048	3,815
80	8	2	4	7813	125	512	15,259	8	4096	1,907
80	8	2	2	7813	63	1024	7,629	8	8192	0,954
80	8	2	1	7813	31	2048	3,815	8	16384	0,477
80	4	2	1	7813	16	4096	1,907	8	32768	0,238
80	2	2	1	7813	8	8192	0,954	8	65536	0,119
80	1	1	1	7813	8	16384	0,477	8	131072	0,060
40	1	1	1	7813	8	65536	0,119	8	524288	0,015

Table 1 Some specific examples of the 2GC system[3].

The current ALMA system provides 64 antennas of 12 m. The 2GC design will accommodate also the ALMA Compact Array (ACA), which consists of 12 antennas of 7 m. Furthermore 4 extra 12m antennas are added for calibration purposes. Hence, the total number of antennas is set to 64+12+4=80. To cope with extensions in the future, the internal interconnect infrastructure of the correlator sub-system at the board level is designed for 96 antennas.

The total number of spectral channels required per baseband, per polarization product and for each baseline, is 1024. All four Stokes parameters are measurable with the 2GC and require over 8 GHz bandwidth a total of 4 x 4096 spectral channels for each baseline. The technical top level requirements are summarized in Table 2. These requirements are in line with the specifications and goals formulated by the ASAC [3].

[3] 34 overlapping subbands are implemented (see Table 2) to provide 32 effective subbands.

Item	Quantity	Unity
Number of antennas	80	
Number of polarizations / baseband	2	
Number of basebands / polarization	4	
Baseband bandwidth	2	GHz
Number of subbands / baseband	34	
Max. subband bandwidth	62.5	MHz
Min. subband bandwidth	7.8125	MHz
Spectral channels / subband	32	
Total spectral channels / baseline	16384	
Number of digitizing bits	3	
Number of correlation bits	3	
Number of subarrays	8-136	
Minimum integration time	1	ms
Phase switching modes	90+180	degrees

Table 2 Top level requirements of the 2GC system.

2.3 Top Level Assumptions

In this section the main assumptions for the design of the 2GC are listed:

1. Fine delay tuning in the sample clock is implemented with an accuracy of <°1/32th sample and a range of +/- 0.5 sample. This is discussed in [2] and [4].
2. It is assumed that the input data of the 2GC is re-synchronized properly with the fixed system clock after fine-delay stepping (fine delay stepping is implemented at the antennas and the bulk delay is implemented in the main building).
3. A power level independent A/D converter with Automatic Gain Control (AGC) is required to avoid discontinuities in the spectral baselines after stitching together the baseband spectra.
4. The power in front of the A/D converter has to be detected. This information is used for the de-normalization process.
5. Every frame cycle a header must be inserted in the data stream. Header injection is used in the 2GC architecture to prevent large control loops around the system. In this way the parameters and specific measures (of e.g. power levels) are available at any stage in the data path. Each stage in the 2GC design can extract the header. A sub-system can also add information. The filter sub-system for example has to add power level information per subband to the header and subband identification information (e.g. used centre frequency and bandwidth).
   The header should contain the following information:
   a. Baseband power level, measured in front of the A/D converter.
   b. Identification of antenna, baseband and polarization.
   c. Fine-delay information.
   d. Reference level information.
   e. Time tag.
   f. Synchronization information.
   g. Etc.

6. Baseband switching is implemented in the analog-processing block or in the digital transmission. In this way one or more basebands can be routed to the correlator resources of the unused basebands. In the extreme case, all correlator resources can be routed to a single baseband.
7. In the post-processing stage the subbands and basebands are stitched together and de-normalized (identification and power information to de-normalize is sent to the post-processing stage). This is a post-processing assumption, because the real-time constraints are relaxed after correlation.

3 Interface Requirements

In this section the hardware and software interface requirements are described briefly. Detailed interface descriptions are not covered in this document. Some interface requirements and especially the synchronization requirements are dependent on the 2GC system location.

3.1 Hardware

The hardware interface requirements are:

Input signal requirements:
The data input of the 2GC system is a de-multiplexed data signal of 3 bit and at 125˚MHz. The header information is included in the data signal.

Output signal requirements:
The correlator system will deliver normalized correlation coefficients in contiguous lag order. The minimal integration time and the total number of lags determine the maximum data rate to the post-processing stage. Provisions must be made to reduce the data rate to a manageable data rate for the post-processing stage, but in a way that the reduction can easily be adapted to upgrades of the post-processing stage.

Control signal requirements:
The (real-time) control interface of the current base line correlator will be used as much as possible. This must be extended for the 2GC, for covering all the additional flexibilities.

Reference signal requirements:
A number of reference signals are required for the operation of the 2GC. For this the present interface with the base line correlator can be used.

3.2 Software

The software interface of the current base line correlator will be used as much as possible. This must be extended for the 2GC, for covering all the additional flexibilities. In fact the basic observing modes will be the same for the baseline correlator and the 2GC correlator. However, we will offer higher resolution and sensitivity and flexible assignment of spectral windows through the bandwidths. The software interfaces can be categorized in:

Configuration interface
This interface is used to specify the observation mode of the correlator hardware by means of a limited number of observational parameters. This produces a set of static parameters to be sent to the hardware prior to the start of an observation.

Control interface
The control interface concerns the transfer of parameters that change during an observation (for example delay tracking, status information).

Data transfer interface
This interface handles the transfer of correlated data from the correlator to the data destination in a format generated by the configuration interface.

Test software
Test software will be necessary to exercise the hardware at module, unit and system level.

4 References

[1] Atacama Large Millimeter Array project book, December 2000, URL: http://www.alma.nrao.edu/projectbk/construction/

[2] A. Bos, A system design study of the ALMA correlator. Report nr: Report-001 ASTRON-28000-R1. ASTRON, Dwingeloo, the Netherlands , October 2002.

[3] Report of the ALMA Scientific Advisory Committee: September 2001 Meeting, October 15, 2001, URL: http://www.eso.org:8082/committees/ASAC/asacreport_2001Sep.pdf.

[4] A. Baudry and A.W. Gunst, ALMA Filter Bank Specifications and Delay Tracking. Report nr: Report-006 ASTRON-28000-R1. ASTRON, Dwingeloo, the Netherlands, November 9, 2001.

[5] B. Quertier, A.W. Gunst, Comparison of FIR filter bank architectures, September 2002. URL: http://www.observ.u-bordeaux.fr/public/alma/2GC/.

[6] G. Comoretto, Design of a FIR filter using a FPGA, Arcetri Technical Report no. 5/2002 revision 2.0, November 2002, URL: http://www.arcetri.astro.it/~comore/Report_4a_2002.pdf.