Astronomical Data Analysis Software and Systems XIII
ASP Conference Series, Vol. 314, 2004
F. Ochsenbein, M. Allen, and D. Egret, eds.

ALMA On-Line Calibration Software

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Abstract. On-line calibration consists of calibration operations performed to maintain the ALMA observing system properly tuned to successfully execute the planned observations. The results are used in quasi-real time by the observing process, but also as input by hardware quality control, by the dynamical scheduler, and by the Science Pipeline. Among processing operations are the calibration of the atmospheric absorption, of phase radiometric correction, of pointing scans, of phase and amplitude reference measurements, ... We describe the developments as planned and the options taken so far.

1. Introduction

On-line calibration consists of calibration operations that are performed to ensure that the ALMA system is and remains properly tuned to successfully execute the observing projects as they are scheduled. Many of these calibrations are to be reduced on a short time scale (0.5 second), so that the calibration results are made available to the observing process (**Control Subsystem**) which, in those cases, is waiting for those to continue and acquire data.

Results are also used by the **Scheduler**, which needs to be kept informed, as the quality of the calibration is one of the main factors determining which project is best observed at a given time, and by the **Executive Subsystem**, to maintain a proper hardware quality control.

Results are displayed and used by the **Quick Look Pipeline** and stored in the **Archive** for further use in the **Science Pipeline** which will prepare the final science results.

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On-line calibration is implemented by the **Telescope Calibration Subsystem** of ALMA Computing.

2. Calibration Operations

We outline here the main calibrations to be performed:

2.1. Atmosphere calibrations

At frequent intervals (1-10 min), we need to compute atmosphere-corrected system temperatures, to be used later, by the quick-look and science pipelines, to scale raw data into antenna temperature scale. These system temperatures need do be calculated for every ~ 100 MHz frequency interval within the 8 GHz wide instantaneous passband. At this occasion we compute also receiver temperatures, optical depths, and other atmospheric parameters. The actual calibration mode, including the hardware device being used, is being planned by the Science team. This calibration needs previously measured side band ratios as input.

We will also need specific measurements to calibrate the Water Vapour Radiometers (WVR). From those we will derive path length correction coefficients to be used in real time by the Correlator Subsystem to apply an on-line path length correction to visibility data, at $\sim 0.5-1.0$s intervals, prior to integration.

Both calibrations will use the atmospheric library (ATM) developed at IEM (Madrid).

2.2. Phase calibration

At regular intervals, phase calibrators (point sources) are observed. This can be very frequent (~ 20s) when the atmosphere is not stable, e.g. when observing at high frequencies. For each phase calibrator observation, we will measure the rms phase fluctuations as a function of baseline length to qualify the atmosphere, for instance by determining a seeing parameter. Using the last few such measurements, we will determine a provisional calibration curve, to be used by the Quick Look pipeline to prepare an on-line display of the science result. The goal is also to compare data with and without path length correction, in order to determine the on-line path length correction validity, and refine empirically the correction coefficients.

2.3. Amplitude calibration

At less frequent intervals amplitude calibrators will be observed. On these we will measure antenna efficiencies as a quality check, to get an early warning on phase de-correlation, pointing or focus problems, receiver problems. Using the last few measurements, we will determine a provisional amplitude calibration curve (to be also used by the Quick Look pipeline). Also comparing data with and without applied path length correction will give information on the validity of the on-line path length correction.

2.4. Pointing and focus measurements

Reference pointing will be needed at typically at ~ 30 min. intervals to obtain the required pointing accuracy ($0.6''$). These measurements will be made on point sources, at most a few degrees from the target. We will use five-point, cross or circular scanning, interferometer mode measurements to determine collimation offsets for each antenna. Similar but less frequent measurements will be used to determine focus offsets in axial direction.

Sets of pointing measurements on sources in very different directions will be used to determine the pointing model coefficients by means of a least square fits. We may also determine quite frequently a local pointing model, to be used for e.g. $2-3$ hours, as an alternative to the more frequent reference pointing measurements.

2.5. Side band ratios measurements

Side-band ratios will need to be measured at regular intervals (receiver retunings), even when the image sideband is separated or rejected electronically, in order to determine the system temperatures. This is essential e.g. for precision single-dish spectroscopy. Measurements will use a strong continuum source in interferometer mode; the ratios will be sampled at $\sim$ 100MHz frequency intervals.

2.6. Delay measurements, antenna position determinations

These less-frequent calibrations are needed whenever hardware connections are made (delays) or when antennas have been moved in the continuous array reconfiguration scheme. They use strong continuum sources in interferometer mode. The delay calibration need spectral information (with a resolution depending on the delay errors; The antenna position calibrations need a number of sources across the visible sky.

3. Interfaces and Packages

The following table summarizes the interfaces between on-line calibration and the other parts of ALMA Software:

Subsystem		*Description*		*Subsystem*
Executive	→	Lifecycle, parameter tuning		
OffLine	→	Off-line execution		
Control	→	Inform that new data is available		
Control	→	Observation Meta/Auxiliary data		
Correlator	→	Observation Channel Averaged Data		
Correlator	→	Observation Spectral Data		
		Publish Results (new observing parameters)	→	*Control*
		Publish Results (quality parameters for scheduling)	→	*Scheduler*
		Publish Results (new calibration data)	→	*QL Pipeline*
		Publish Results (quality data)	→	*Executive*
		Archive Results (all kinds)	→	*Archive*
		Error, Alarm	→	*ACS*

4. Issues

Science requirements, in particular in the area of calibration, will still evolve in the near future, as the calibration plan is still being finalized, as for instance the best use of water vapour radiometry and of fast-phase referencing can only

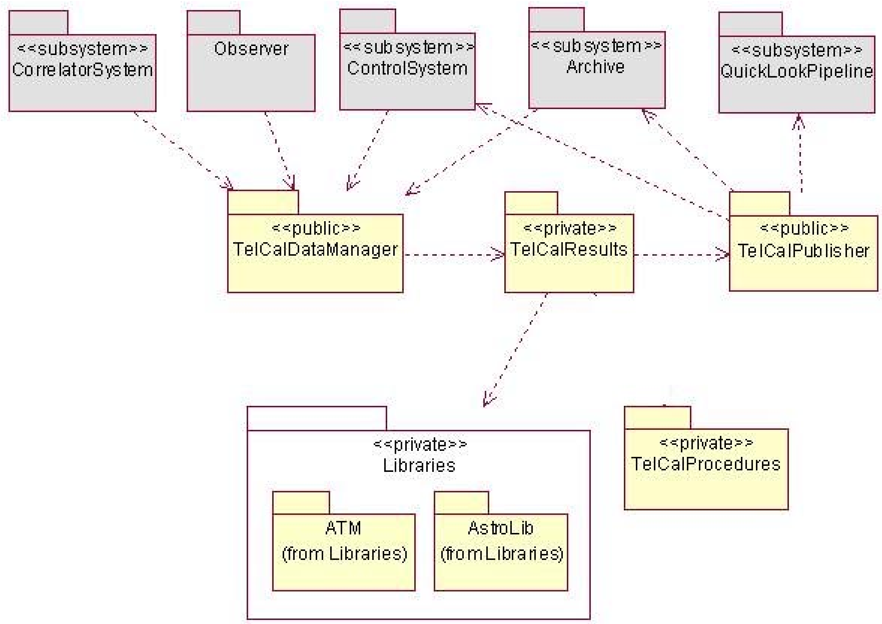

Figure 1. The package structure of On-line calibration software.

be determined after first on-site testing. As a consequence the developers will work in close collaboration with the Science team. In the mean time tests of the calibration software will proceed using both simulated data and data from the antenna prototypes.