Atacama
Large
Millimeter
Array

Delay Calibration Steps

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Specification Document

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1 Goals

1. The goal is to measure the delay offsets induced by the hardware, in the antenna, fibers, cables, ... These delays have to be compensated by appropriate delays in the correlator to limit amplitude losses due to de-correlation across the bands.

   Note, however, that small (i.e. a fraction of a nanosecond) and constant delay errors will be efficiently removed by bandpass calibration.

2. The *basic experiment* is simple enough: measuring the delay on a strong point source is done simultaneously for each base-band and polarization, having the correlator producing the two parallel products (XX and YY).

   The delay is determined by fitting a linear dependence on frequency for the antenna-based channel phases. It might be wise to exclude a few edge channels in each base-band. The bandwith should be 2GHz for each baseband to optimize sensitivity.

   However if the delay is totally unknown and can be high, a narrow band on a strong source is preferred, as a strong delay could produce too much de-correlation in wide channels; for instance in 1MHz channels the delays are measured with an ambiguity of 1ms. With BBC 7 (2 GHz and 2 polarizations), the resolution is 15.625MHz and the ambiguity is 64ns. This is the equivalent of 20 m distances. If the fiber lengths are not known from construction to that accuracy, we will have to use use higher frequency resolutions.

2 Parameters to be calibrated

1. There are in fact four kind of parameters to be measured:

Quantity	Description	Number	When?
$\tau_{\rm R}$	Receiver delay	$N_{\rm ANT}N_{\rm BAND}N_{\rm POL}N_{\rm SIDE} = 2560$	Receiver or down converter change
$\tau_{\rm IF}$	IF delay	$N_{\rm ANT}N_{\rm POL}N_{\rm BB} = 512$	Antenna move, back-end change
$\tau_{\rm XP}$	Cross Polarization delay	$N_{\rm BAND}N_{\rm SIDE}N_{\rm BB} = 80$	At least once, but should be checked from time to time.
$\tau_{\rm LO}$	LO Propagation delay	$N_{\rm ANT}(N_{\rm BB}+1) = 320$	Antenna move, back-end change, Power reset.

   The LO propagation delays affect the phases only when the LO frequencies are stepped, e.g. for Doppler tracking. If the LOs are kept at a constant nominal frequency, they will produce constant phase differences that will be removed by phase referencing. They can be measured by stepping the LO's by a fixed amount and measuring the observed phase changes on a point source calibrator.

   With respect to corresponding chapter included in the calibration Plan, I have simplified this table as tracking all the parameters is probably needlessly complex and error-prone. It had been proposed there to keep track on the differential delays between base-bands independently of the station-dependent delays due to fiber lengths. However the possibility of rather frequent use of ACA antennas with the 64-station correlator made this even more complex. It is not very costly to measure all the baseband delays whenever the interferometer configuration is changed.

2. It seems however worthwhile to keep track of receiver delays, as a lot of trouble can be avoided by having a reliable prediction of the delays in the high frequency bands from measurements in low frequency bands, e.g receiver band 3.
3. Technically the splitting point between the two parts is the switch in the down-converters, so the receiver delay includes not only the front-ends, but also the cabling between the IF processing assemblies and part of the down converters, which are common to all receiver bands.
4. The same set of τ_{R} for an antenna should be valid whether it is connected to the 64-station correlator or to the ACA correlator. But the set of τ_{IF} is correlator dependent (there is one such set for each correlator). This also applies to the set of cross correlation delays τ_{XP}.

3 Calibration steps

3.1 Initial Steps

1. We need to have approximate values for the fiber lengths to the pads (to a few meters, say 10m or about 30ns). These will be the starting values for the τ_{IF}.
2. Use receiver band 3:
   - Set (initially) all $\tau_{\mathrm{R}} = 0$ for receiver band 3, e.g. for upper side band output. The system can be set in side band rejection mode (using frequency offsets).
   - Measure a strong point source with all available base-bands set to maximum bandwidth.
   - The measured delay errors (obtained by least-squares fitting a linear frequency dependence $2\pi\nu\tau_{\mathrm{IF}}$ in the observed spectral phases) will give the actual τ_{IF} values. As we always measure delay differences, we can set all the $\tau_{\mathrm{IF}} = 0$ for one reference antenna. Alternately we can set the sum of all τ_{IF} for reference antennas to be zero.
3. Process now with the other available receiver bands:
   - The same measurements are done in turn for USB and LSB. But now the τ_{IF} values values are known, and the measurements give the τ_{R} values.
   - Again we can set $\tau_{\mathrm{R}} = 0$ for the reference antenna, or set the sum of all τ_{R} to zero.
4. For receiver bands with a single DSB output, we can either use side band rejection or side band separation, as the τ_{R} values should in that case be the same for both side bands.
5. Finally the same sets of measurements have to be repeated, for all bands, on a polarized source, with the correlator set to generate cross-polarization products, to get the τ_{XP} values.

3.2 Routine measurements

1. After an antenna move, or a connection change (e.g. swapping correlator inputs, of swapping an ACA antenna for a 64-array antenna), one needs only to do one measurement (e.g. with two polarizations, four base-bands, on the same sideband or receiver band 3 for maximum sensitivity). Since some antennas have not been moved, and some antennas have been moved, all measured delays should be referred to the average on unmoved antennas.

2. After an intervention in one antenna (receiver exchange) one should remeasure the $\tau_{\rm R}$ for the new receiver. This will be done relative to band 3 or to another low frequency band that has been previously measured, if by chance band 3 is not available on all antennas.
3. In theory the cross polarization delays $\tau_{\rm XP}$ need to be measured only once (for each correlator), as we always measure delays for each polarization relative to previously measured signal paths in one or a set of antennas. In practice they should be all checked from time to time.
4. If Doppler tracking is to be used the LO propagation delays need to be remeasured whenever there has been a system reset or power failure.

References

[1] SSR Committee, ALMA Science Software Requirements and Use Cases, ALMA-70.10.00.00-002-I-SPE

[2] ALMA Calibration Plan (2004-10-07 Draft), SCID-90.03.00.00-001-A-PLA

[3] ALMA Calibration Specifications and Requirements (2004-10-07 Draft), SCID-90.03.00.00-007-A-PLA

[4] Specifications and Clarifications of ALMA Correlator Details, Stephen Scott, 2003-01-29, AlmaCorr.pdf