Atacama
Large
Millimeter
Array

Bandpass Calibration Steps

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Specification Document

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Change Record

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1	2005-10-13	Robert Lucas	All	Initial Draft
2	2007-08-14	Robert Lucas	All	Changes after SciIPT review

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Contents

1 Goals

The goal of bandpass calibration is to correct the science data for all frequency-dependence of the telescope gains. In more detail:

1. Correct for the frequency dependence of the atmospheric attenuation. This is a pure amplitude calibration, using a dual load system: ambient and warm loads, at $T_1 \sim 293$ K and $T_2 \sim 350$ K (about 80 C). This is described in [5]. Using a suitable linear combination of the two load signals allows to have T_{CAL} very much independent of frequency (as well as of changes in atmospheric optical depth).

   This steps corrects also for frequency dependence of the amplitudes of antenna-based gains in the electronics. However it does not correct for the frequency dependence of antenna and optics losses, prior to the amplitude calibration device; such a correction requires a celestial source to be observed.

2. Measure the relative phases (and amplitudes) of the basebands on a celestial point source. This is required to improve the signal-to-noise ratio for the various on-line calibrations, like pointing, focus, which are done on point sources (quasars), and for which we will average basebands, side bands and polarizations. For this purpose only one frequency point for each baseband is needed.

3. Measure the sideband amplitude ratios as a function of IF frequency. This is needed for proper calibration of the atmospheric amplitude attenuation, and conversion to T_{A} scale, as this gain ration g enters the formula for T_{CAL}, in both two-load and single-load schemes. (See [5]).

4. Correct for bandpass shape in science data. This is done in both amplitude and phase using the signal of a strong point source. This is needed to correct for:

   (a) The phase response of all the analog receiving system, with the exception of the effect of delay offsets which have to be corrected before observing (see [6]). The phase response of the digital Tunable Filters is corrected for in real-time by the correlator software.

   (b) The amplitude frequency response not corrected by the amplitude calibration above. Two effects should contribute:

      i. The amplitude response of the antenna beam (antenna gain).

      ii. The decorrelation, due to averaging in time (atmospheric or instrumental phase fluctuations), which should not be frequency dependent, or frequency (the latter should be small except may be at the very edge of filters).

2 Calibration steps

Phasing the base bands: We observe a strong point source at the calibration frequency and at the observing frequency to measure the relative phases of the basebands (for both polarizations). At both frequencies we expect to have a 1 Jy source visible at all times. At 90 GHz the integration time is a fraction of a second. At the highest frequencies it can be up to 15 seconds, for a 2 antenna system.

I believe this step can be done in all scheduling blocks. One would probably do it at the calibration frequency first, then at the observing frequency (after pointing and focus have been optimized at the calibration frequency).

The result will be used for all calibrations for which maximum sensitivity is required. For instance for pointing at the calibration frequency we will correct for the relative phases of base bands before averaging them.

Measuring the side band ratios: This is explained in detail in [7]. The calibration requirements have been relaxed in relative accuracy since (1% and 3% at mm and submm wavelengths respectively), but the time needed is still about 8 minutes to measure the side band ratio at 250MHz sampling on a 1.5Jy source at the highest frequency.

In summary, both the receiver sideband ratio g and the atmospheric side band ratio $e^{\tau_s-\tau_i}$ have to be known. A direct measurement on a single source gives only the product $ge^{\tau_s-\tau_i}$. So there are two policies:

1. Trust the atmospheric model for $e^{\tau_s-\tau_i}$. This is probably good enough for most if not all projects. As stated in [7], the dependence of g on IF frequency is probably quite small for ALMA receivers. So one could do the measurement of g with a coarser frequency sampling (may up to be 2 GHz, i.e. one value for each base-band). Then the ratio measurement can be done in a relatively short time.
2. For some high precision projects, implement the method described in [7]: observe two strong sources at different elevation, allowing to determine separately g and $e^{\tau_s-\tau_i}$. This is more demanding in integration time, but it is worth to try, at least during test time, since it is an independent check of the validity of the atmospheric model.

Calibrating the bandpass for each base-band: This is the 'classical' bandpass calibration for interferometers. This is done in the following way:

— A strong source for which the frequency dependence of the visibilities is observed with the same setup as the target source. It is easier to use a point source of known spectral index, but a strong source for which a good model is known may be used.
— Using the observed visibility spectra, and the known model for the source visibilities, the bandpass curves are derived for each base band. The bandpass curves may e.g. be expressed as antenna-based frequency dependent polynomials for amplitude and phase.
— These bandpass curves will later be correct further source observations for the frequency dependence of the complex gains.

As explained in [7] the bandpass calibration is time-costly at high frequencies, even though it needs only to be done at low frequency resolution (a few times 10 MHz, depending on the required phase precision), as the computable bandpass shape of the digital filters is corrected for in real time by the correlator.

There is good hope to save observing time, as:

1. all electronics after the second LO are used at the same frequency for all projects:
2. one has the possibility to switch the sky frequency while keeping the same tuning for the second local oscillators.

For instance one could measure the bandpass phases, with typically 10MHz resolution, on a strong source at low sky frequency and apply them to the high frequency data. If the LO2s are kept at the same tunings, then this should correct for the IF contribution to the passband phases.

The main issue here is whether the remaining RF contribution is smooth enough as a function of frequency so that it can be determined at the sky frequency using a lower frequency resolution (e.g. a few 100MHz), requiring only a few minutes of integration on a 1Jy source. Only tests with the actual antennas and receivers will teach us this.

In particular, changing the IF attenuators to correct for varying levels of atmospheric emission may affect the IF bandpasses. This could limit the validity of the bandpass calibration to the time span between such IF attenuation changes. Ideally the frequency response of these attenuators could be measured in the lab or on a very strong source to allow more flexibility in the use of bandpass calibration (and save observing time at the high frequencies).

References

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[5] Amplitude Calibration Steps, R. Lucas and Jeff Mangum, 2005-09-15, AmpliCalStepByStep.pdf

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