Frequency Switching on ALMA

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Atacama
Large
Millimeter
Array

Change Record

Version	Date	Affected Section(s)	Change Request #	Reason/Initiation/Remarks
A	2005-05-03	ALL	Draft A	Initial version A. Wootten from collected email comments..

Table of Contents

1. Scope and Description

This document discusses the implementation of frequency switching on ALMA. Although frequency switching is not specifically listed among the primary requirements in the ALMA Scientific Specifications and Requirements Docment (ALMA-90.00.00.00-001-A- SPE), it immediately derives from several principles listed in that document, namely:

> ALMA shall maximize sensitivity over its frequency bands [SCI-90.00.00.00-0110-00, SCI-90.00.00.00-0120-00, SCI-90.00.00.00-0130-00, SCI-90.00.00.00-0140-00, SCI-90.00.00.00-0150-00, SCI-90.00.00.00-00040-00, SCI-90.00.00.00-00160-00, SCI-90.00.00.00-0200-00];
> ALMA shall maximize the flexibility of spectral line capability [SCI-90.00.00.00-00030-00, SCI-90.00.00.00-0040-00, SCI-90.00.00.00-0050-00, SCI-90.00.00.00-0060-00];

Specifically, frequency switching is a particular case of intraband tuning, [SCI-90.00.00.00-00040-00] which states: 'It shall be possible to retune ALMA to a second frequency within a band from a first in the same band in a time not greater than 1.5 seconds. Switching between two frequencies less than 0.025% apart shall take no more than 10 ms. Note that this applies to switching within (rather than between) bands.'

1.1 Applicable documents

The following documents are included as part of this document to the extent specified herein. If not explicitly stated differently, the latest issue of the document is valid.

Reference	*Document title*	*Date*	*Document ID*
[AD1]	ALMA Scientific Specifications and Requirements	2005-03-23	ALMA-90.00.00.00-001-A- SPE

Table 1

1.2 Reference documents

The following documents contain additional information and are referenced in this document.

Reference	*Document title*	*Date*	*Document ID*

[RD1]	List of acronyms and glossary for the ALMA project	--	ALMA-80.02.00.00-004-A-LIS
[RD2]	ALMA Project Book	2002-02-20	Version 5.5, 'ALMA Requirements and Specifications'
[RD3]	Science with a Millimeter Array	1983	Various, MMA Memo 2
[RD4]	Recovering line profiles from frequency-switched spectra	1997	Astronomy and Astrophysics, 124, 183
[RD5]	Single-Dish Radio Astronomy: Techniques and Applications	2002	Stanimirovic, S., Altschuler, D., Goldsmith, P., & Salter, C. ASP Conf. Ser. **278**

2. Discussion

A basic principle underlying the ALMA Science Specifications and Requirements is that sensitivity be maximized [RD2, RD3]. In a total power continuum mode, this may be done in a number of ways, including increasing the instrumental bandwidth. The latter is not available for total power spectroscopic observations. Frequency switching is ***the*** most efficient single dish spectroscopic observing mode [RD4, RD5]. All observing modes require a comparison of an "on" source state with an "off" source state for maximum cancellation of drifts and instrumental offsets. In frequency switching, the instrument is tuned onto the line for the "on" portion of the cycle, and off of the line at an adjacent frequency for the "off" portion of the cycle. When sufficient bandwidth is available (as is the case with ALMA), both portions of the cycle may lie within the bandpass, allowing a reconstruction of the spectrum with $\sqrt{2}$ more sensitivity than if the "off" were outside the instrumental bandwidth or at a different position on the sky. An alternate option for increasing the sensitivity of the array by such a factor would be to increase the collecting area through supplementing the number of telescopes by this factor. This would be a very expensive route to take and provides a measure against which to compare the cost of adding a frequency switching mode to the array. Further, for observing terrestrial atmospheric lines, or those in the Lascar plume - which are of interest for atmospheric and vulcanological physics, but also for some calibration issues - frequency switching is the favored mode; one cannot position-switch against blank sky, because the atmosphere is more or less the same in all directions. The same argument also holds for extended emission; any smooth emission that extends over about one primary beamwidth or more is resolved out by even the shortest interferometric baselines, so some form of total power observation is essential. For such extended emission, frequency switching may be the only switching mode available for the observations.

2.1 Frequency Switching: a total power mode only

Frequency switching is only a total power only activity not used at all in interferometric modes and it is necessary for it to be employed on every telescope in the array. Therefore phase tracking across the frequency step is not necessary. It is conceivable that one could phase the array to gain sensitivity and then frequency switch the phased array, a mixed interferometric and total power mode. According to M. Wright, there were attempts to observe in this mode with the BIMA instrument. However, phased array frequency switching is not a supported mode for ALMA.

2.2 Cadence of Frequency Switching

The goal of switching is to cancel out variations in the atmosphere or in the instrument. The finite diameter of the antenna acts as a smoothing filter on atmospheric variations; an upper limit to the cadence of the cycle could be taken as the atmospheric crossing time for the antenna. At the Kitt Peak 12 Meter, a 1-second switch cycle was typically used. A minimum limit to the cadence is given by the system clock; the system must be retuned to the new frequency in a time small compared to the system clock cycle (there will be a blanking time associated with each switch cycle to account for the time needed for the system to reach stability). The minimum clock cycle is 48 msec; the time for the retuning of the system must be small compared to this and is given in SCI-90.00.00.00-00040-00 as 10 msec. The actual time should be much less than 10 msec if that is possible, however the amount of the frequency switch is a fixed percentage of the sky frequency; lock must be reacquired within this time interval and this may prove difficult the higher the frequency offset (as the frequency is higher).

One possible mode of frequency switching would be to employ it while doing ‘On-the-Fly’ (OTF) observing. This mode would require very fast switching, fast compared to the 1ms autocorrelation sampling time of the correlator. In OTF observing, an ‘Off’ is observed only periodically, making this a very effective mode of observation already, with little benefit gained by employing frequency switching also. Given the difficulty of switching so fast, the minimal return in sensitivity seems unwarranted. This mode will not be employed on ALMA.

2.3 Amplitude of Frequency Switching

An old specification requires that a change of .03% of the sky frequency be accomplished within 10 msec (indeed, this was item #431 in 'System Technical Requirements' 80.04.00.00-004-D, now obsolete). At a review of the Central Variable Reference in Charlottesville, it was noted that this is difficult to achieve at the highest frequencies; it was suggested that the amplitude be relaxed to 0.025% of the sky frequency. This corresponds to 75 km/s at any frequency. The previously adopted value of 0.03%

corresponded to 90 km/s, or three channel spacings with the broadest band mode of the correlator at the lowest implemented frequency for ALMA. The availability of the tunable filter bank allows many more channels and narrowest available filter bandwidth is no longer a constraint. Note that one does not need to switch entirely off of the line signal to recover the signal [RD4]. The Science IPT agrees to this change.

2.4 Precision of Frequency Switching

The ripples in the frequency response of the feed horn or of the antenna itself will not be cancelled by frequency switching. A standing wave ripple usually dominates the antenna frequency response, typically coming from coherent noise being radiated out of the receiver feed horn and reflecting back into the feed after bouncing off the subreflector, feed struts or other structures. This causes a variation in the receiver input noise, typically dominated by a sinusoid corresponding to the path length involved in the strongest reflection. With frequency switching, if the precise switching frequency interval is made to match an integer number of periods of this dominant sine wave, the sinusoidal ripple is effectively filtered out, and the spectral baseline is very much better. The astute ALMA observer would like to match the frequency switching interval to this standing wave. The period is likely to be around 25 MHz (say, a 12-meter round trip reflection from the receiver to the subreflector), and that clever observer would like to match a multiple of that within, say, 1 per cent. Therefore the switching distance should ideally be settable to within 0.25 MHz. This precision in setting the frequency switching distance, defined as a fixed fraction of a MHz, is independent of observing wavelength.

2.5 Placement of the Frequency Switching Active Element

A goal of frequency switching is to cancel as many instrumental variables as possible. The system is most stable if the receiver can be held constant between the two switch cycles; in this case all the slopes and ripples in the receiver passband, due to the receiver frequency response itself, cancel as perfectly as possible. Switching of the 1st LO achieves the best cancellation of these effects. The only thing that doesn't cancel is the noise spectrum before the mixer, which includes antenna spillover noise, atmospheric noise, and the desired astronomical signal. This allows one to observe the astronomical signal, while canceling out the strong ripples, slopes and drifts occuring in anything in the receiver system after the first mixer.

Consider switching of the 2nd LO. In this case, one effectively moves the IF filter response of the first IF back and forth on the sky. This has two bad effects on the resultant spectrum:

1) the IF filters and other circuitry will not have a perfectly flat frequency response. When the two phases of the 2nd LO switching cycle are subtracted, a shifted version of the 1st IF response will be subtracted from itself. As it is shifted, it cannot cancel

completely. Worse baselines must result, even in the total absence of atmospheric effects.

2) the total usable spectrum width is reduced by the switching range; the edge of the spectrum is going to fall outside the IF filters in one phase of the switching cycle. If we're trying to look at a spectrum that's more than 2 GHz wide, we're going to have to arrange the different 2-GHz 2nd IF bands to overlap by more than the switching distance.

Thus, in 2nd LO switching it will not be possible to distinguish between spectral features in the first IF amplifiers and filters, and *astronomical* spectral features. Remember, these IF slopes and ripples are multiplicative factors on the entire system noise. If one tries to observe a milliKelvin astronomical signal, which will often be the case, it will have to be done in the presence of ripples which may be effectively many tens of degrees in amplitude - say, 40 dB to 50 dB stronger than the signal one is trying to see.

Frequency switching should be supported in the 1st LO on ALMA.

2.6 Frequency Switching on the Atacama Compact Array

The Atacama Compact Array (ACA) is devoted to obtaining total power data for ALMA. One element of its composition is a set of four 12m antennas which must be usable in the main array for calibration and other purposes. Since these antennas must be interchangeable with antennas in the main ALMA array, they must support frequency switching. The second compositional element of the ACA is a set of twelve 7m antennas. As the inherent sensitivity of these antennas will be inferior to that of the 12m antennas, all means should be taken to increase their efficiency. One of the simplest means of increasing efficiency, as discussed above, is through employment of a frequency switching mode. The twelve 7m antennas of the ACA must therefore also employ a frequency switching mode.