EOC Memo: General Considerations & Observing Scenario for Bandwidth Switching Observing Mode

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1 Introduction

This memo presents some general considerations ALMA Cycle 3 Bandwidth Switching (BWSW) oserving mode, the defining characteristic of which is the collection of calibration data in a different spectral configuration from the science targets.

In order to help identify assumptions and implications for ALMA subsystems, including the analysis pipeline, a BWSW observing scenario is presented (§ 3).

2 General Considerations

2.1 Spectral Constraints

It is helpful to consider the set of spectral constraints that exist. For cycle 2 (ALMA Cycle 2 Proposer's Guide v1.8 & Technical handbook, v1.1) these are:

- There may be up to 4 basebands (BB), each by definition 2 GHz wide.
- There may be up to 4 spectral windows (SPW) per baseband.
- Within one baseband, all SPW's must use the same correlator mode; these SPWs may however use different amounts of spectral averaging in the correlator.

Because of the prohibition on mixed correlator modes, BWSW can be triggered by use of just four high-resolution FDM modes spaced sufficiently far apart across the receiver sidebands. This minimal BWSW scenario will have four distinct BB, each with one high resolution FDM SPW.

The maximum number of SPWs in cycle 2 is 16 (4 SPW per BB), subject to data rate limitations.
Question: What are the C3 Spectral Constraints?

2.2 Possible Spectral Configuration Sequences

For a given science spectral setup which utilizes all correlator resources and does not provide adequate SNR for calibration, it is necessary to specify what precise spectral setup to use for the calibration observations[1]. Some obvious possibilities are:

1. Keep BB's fixed; replace narrow windows with a single TDM window (one TDM window will cover the entire BB). Alternatively:
2. Same as #1, but instead of keeping the BB's fixed, shift the BB as feasible to optimize atmospheric transmission & stability while maintaining coverage of science SPWs.
3. Use standard continuum windows in the low-opacity/high transmission regions of the receiver band (or potentially, one standard continuum window per BB).

Options #1 & #2 provide the most direct measurement of phase and amplitude corrections in the science SPWs with the penalty that the integration time required to achieve a given SNR in the TDM window on the calibrators would be higher than using the standard continuum bands.

Option #3 would likely provide the highest SNR measurements of the calibration sources. For many ALMA receivers, however, the standard continuum tunings lie at one edge of the receiver bands and/or require very large extrapolations in frequency to reach the far edges of the receiver bands (as much as 70 - 100 GHz for Bands 7 - 9). It is as yet unclear what effect such large frequency extrapolations would have on the gain corrections corrections— in particular, on the real part of the gain corrections *vs.* time. Assuming the primary flux calibrator is also observed with the standard continuum setups, the flux calibration would need

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[1] In this memo, I refer to the science SPW setup as the "FDM setup" and the calibration SPW setup as the "TDM setup".

Band	δf_{sep}/GHz	δf_{extrap}/GHz	F	Notes
3	12	18.5	2.18	-
4	12	18	2.12	-
6	15	42	5.94	-
7	12	68	8.01	-
8	12	95	11.2	-
9	6	77	18.1	Standard cont.SPWs
9b	16	77	6.9	Widest spacing available.

Table 1: SNR degradation factor F of flux calibrations extrapolated from standard continuum bands to the far edge of the receiver band, for each ALMA band.

to be bootstrapped to the FDM windows, probably onto the source used for the SPW-offset measurement sequence. As described in § 2.3, the required extrapolation in frequency is both model dependent and quite noisy at the band edges.

For these reasons the recommendation is to keep the TDM BB's approximately the same as the FDM BB's, with some freedom to shift them to optimize transmission and sensitivity.

2.3 Accuracy of Flux Density Extrapolations Across the ALMA Bands

Using a simple monte-carlo simulation, I evaluated the accuracy of flux calibrations extrapolated from the standard continuum bands to the far edge of the receiver band for each of the ALMA receiver bands. In this simulation the source of interest is assumed to have a simple power-law spectrum whose spectral index is estimated from the standard continuum band measurements and extrapolated to the frequencies of interest. When available, continuum bands in both the USB and the LSB are used. The picture here is that there is one source which has been measured with both the TDM and the FDM setup (the boostrap source), and that the TDM data can be accurately calibrated with respect to an absolute flux standard. We wish to use those TDM measurements to predict the absolute flux density of the bootstrap source in the FDM windows.

Results are summarized in Table 2.3 and are not sensitive to the true source spectrum within the expected range. When available the use of both USB and LSB continuum bands greatly improves results. At the band edges, particularly for the higher frequency receivers, the extrapolated flux density becomes quite uncertain. The SNR of the extrapolated flux density is found to be well represented by a degradation factor F given by:

$$SNR_{extrap.} = SNR_{original} \div F = SNR_{original}\,\frac{1}{\sqrt{2}}\left(\frac{\delta f_{sep}}{\delta f_{extrap}}\right) \tag{1}$$

or

$$F = \sqrt{2}\left(\frac{\delta f_{extrap}}{\delta f_{sep}}\right) \tag{2}$$

Here δf_{sep} is the difference in frequencies between the most widely spaced "standard continuum" SPWs and δf_{extrap} is the difference between the central frequency of the standard continuum bands, and the frequency of the center of the farthest-outlying science SPW. $SNR_{original}$ is the SNR in *one* of the two sidebands (or halves of the total band) used to determine the source spectrum. The SNR is defined as S_{true}/σ, where σ is the measurement noise (for the TDM bands) or RMS of the extrapolated flux values (for the FDM bands).

Assumptions & Caveats: This analysis assumes systematic errors (e.g., relative calibration accuracy between USB and LSB) are smaller than measurement errors; and that the bootstrap source has a spectrum well-approximated by a power law over the range of interest.

2.4 SPW Phase Offsets

Individual SPWs have overall phases which vary between SPWs and need to be measured; test observations have demonstrated these SPW to SPW offsets to be stable over ~ 1.5 hours. The main challenge to determining these offsets observationally is the time variability of the atmospheric phase delay. For a clean measurement of the instrumental phase offsets between spectral windows, the recommended observing sequence is to observe a single source as follows:

1. TDM setup bright source measurement
2. FDM (science setup) bright source measurement
3. TDM setup bright source measurement

The complete cycle of 3 measurements needs to be finished in less than the timescale for the atmospheric phases to change uncorrectibly; i.e., the complete cycle should take roughly the same time (or less) as the time between phase calibrator observations when observing the science target(s). The sequence should be as symmetric in time about its midpoint as feasible in order to cancel linear phase gradients. It is permissible, and likely desirable, for the TDM and FDM measurements to have different scan lengths.

The scans should be long enough to determine the SPW offset to *some specified* accuracy (e.g., the same number as used for determining the phase calibrator observation parameters). Due to the high noise level in the FDM measurements, this TDM/FDM/TDM SPW offset sequence should be collected on a bright source, probably the bandpass (BP) calibrator.

3 Observing Scenario

1. **TDM SPW choice:** the TDM (calibration) SPWs will be chosen to approximately cover the BBs of the FDM (science) SPWs, with some freedom to shift to optimize transmission and sensitivity.
2. **BP observation:** there will be **one** standard bandpass (BP) observation, collected in the FDM setup. The TDM BP will be determined from the phase calibrator observations and/or the TDM scans of the SPW offset measurement sequence.
   (a) **Question**: do we need a special intent for the TDM phasecals since the TDM BP will also be obtained from them?
   (b) **Note on the bandpass solution interval:** To minimize unneccessary calibration overheads & reprocessing effort, the needed resolution needs to be examined and uniformly implemented. Currently the script generator assumes *no* spectral averaging in the BP solutions; the pipeline averages down to 240 channels; and likely the online system assumes something else entirely. For a 60 MHz window, 240 channels gives 250 kHz resolution, which is likely considerably more than most ALMA projects require for their BP solutions.
3. **SPW phase-offset sequence**: As described in § 2.4, there will be a short, 3-scan TDM/FDM/TDM sequence to determine instrumental phase offsets between the TDM and FDM windows. **Questions:** do we want a BWSW-specific intent to identify these scans? What phase accuracy is required for the SPW offset? This is presumably derivable from the standard phase accuracy requirement for the phase calibrators.
4. **Flux Calibration**: A primary flux calibrator will be observed in the TDM setup with the usual caveats (avoid spectral lines in solar system objects).
5. **Main observing cycle**:
   (a) Phase calibrator (TDM setup)
   (b) Science source(s) (FDM setup)
6. At end of observation, optionally repeat **SPW phase-offset sequence** – do this for initial EOC/verification & testing runs at least.