Detecting loss of Coherence based on Telescope Calibration results in ALMA

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ABSTRACT

The ALMA telescope will be composed of 66 high precision antennas; each antenna producing 8 times 2GHz bandwidth signals (4 pairs or orthogonal linear polarizations signals). Detecting the root cause of a loss of coherence issue between pairs of antennas can take valuable time which could be used for scientific purposes. This work presents an approach for quickly determining, in a systematic fashion, the source of this kind of issues. Faulty sub-system can be detected using the telescope calibration software and the granularity information.

In a complex instrument such as the ALMA telescope, finding the cause of a loss of coherence issue can be a cumbersome task due to the several sub-systems involved on the signal processing (Frequency down-converter, analog and digital filters, instrumental delay), the interdependencies between sub-systems can make this task even harder.

A method based on the information provided by the TelCal[1] sub-system (in specific the Delay Measurements) will be used to help identify either the faulty unit or the wrong configuration which is causing the loss of coherence issue. This method uses granularity information to help find the cause of the problem.

Keywords: radio-telescope, coherence

1. INTRODUCTION

As part of the ALMA routine operations, the calibration of the telescope is a critical task which must be performed before a round of observation or when a new antenna element is added or changed into the array. Among the calibrations tasks there is one named Delay Calibration[2] which can also be used for diagnostic loss of coherence issue. Each ALMA antenna, after the down-conversion, produces an output signal equivalent to 16GHz bandwidth signal (signal already digitized); that signal is separated in 8 x 2GHz band-width signals: 4 pairs of signals, each pair are composed by the orthogonal polarizations, see the figure below.

[1] TelCal is the on-line calibration software for the ALMA array.
[2] Delay Calibration is part of the results provided by TalCal.

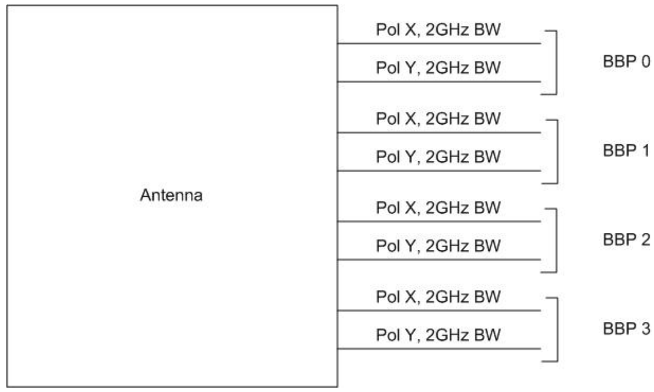

Figure 1, Conceptual view of the antenna output. Here is the antenna is represented as a "black box", its outputs are 8 2GHz bandwidth signals. A pair of orthogonal signals (polarization X and Y) is named Base Band Pair BBP.

The information provided by the Delay Calibration is reported for each IF signal, this information can be used for also helping to figure out the cause of a loss of coherence issue. A loss of coherence problem can be visible in:

- All the Base Band Pairs.
- Only one polarization
- Only One base band pair (both polarization ¼ of the total bandwidth)

The idea of the method presented here is to use the granularity of a loss of a coherence problem to figure out which piece of hardware is not working as it is supposed to be.

This method uses as a principal premise that is more likely to have only one faulty unit instead of more than one faulty unit failing at the same time.

One advantage of this method is that it allows detecting problems in a quick manner and avoids waiting until the data is reduced. This approach enables to face problems as soon as possible and increases the amount of time with most of the array elements working fine.

2. DATA SIGNAL PATH

In this section, a description of how the signal passes through ALMA telescope will be presented, and from there the possible errors and their granularity will be described.

For purposes of providing a view of how the data passes through the ALMA telescope, Figure 2 will be used as a reference. Many details of how the system interacts have been omitted since the main purpose of this sketch is to provide an overview of how the signal is split and processed by each hardware element.

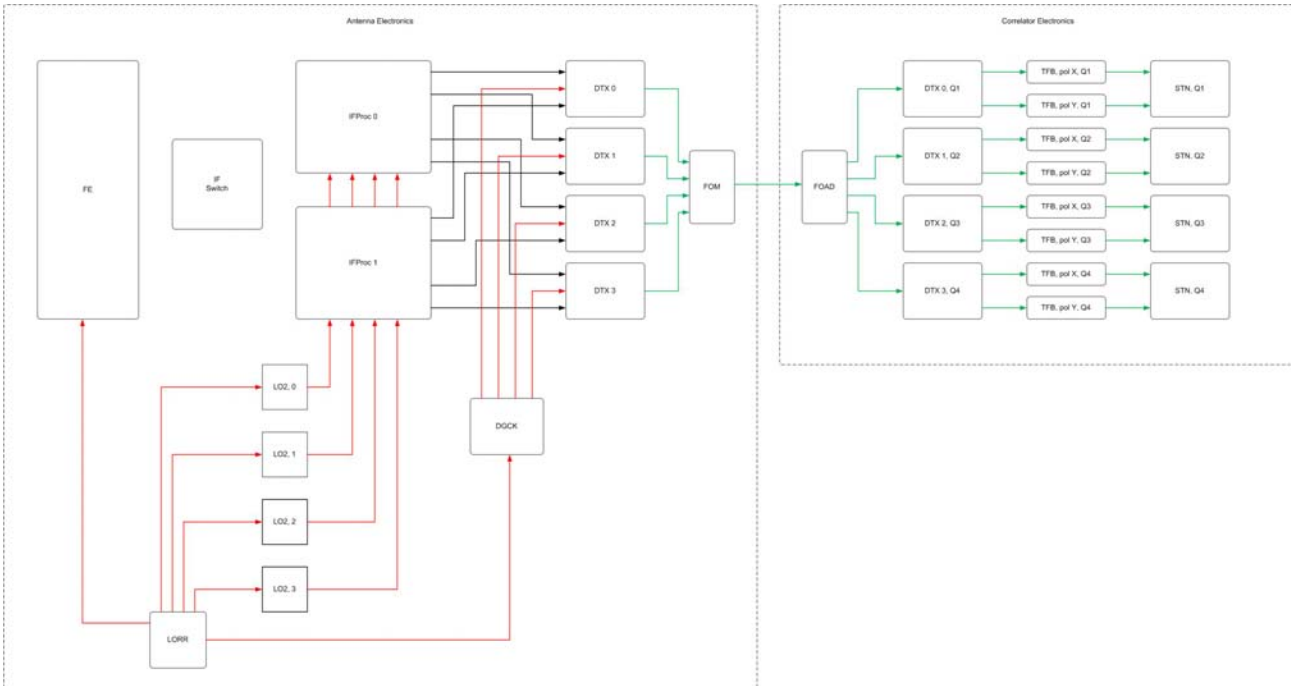

Figure 2, Signal data path, for simplicity many details were omitted for avoiding confusions. The red lines are associated to the timing signals, the green lines are associated to the digital signals, and the black lines are the analog signals

Figure 2 also shows how the different pieces of hardware are interconnected and can be used for determining the granularity of the error if one unit fails. For example, if one IFProc fails, the granularity of the loss of coherence problem will be polarization based.

3. TELCAL OPERATION

The ALMA Telescope Calibration subsystem consists of several calibration algorithms, which are executed and applied to the ALMA datasets in order to ensure that the telescope, as a whole instrument, is and remains in a proper state to observe the subsequent scheduled observations.

Every single calibration data is a process within the online operation workflow, but cat be treated as a non-critical and independent process, from the functional point of view of the whole ALMASW observation lifecycle that means if the calibration data fails, the observation can still be under execution. Currently, calibrations are executed once the phenomena binary and meta-data was acquired and produced by the subsystems involved in the online operation: Control, Correlator (bin) and Data Capture (meta XML), and, can be reprocessed using the offline implementation of TelCal.

The logic calibration purpose is composed by a ScanIntent [3] and DataOrigin [3] specified by the observation process, which basically define the type of calibration needed for the observed dataset: amplitude, atmosphere, bandpass, delay, flux, and the origin of the data (TP, SFI): total power, wvr[3], channel average auto, channel average cross or full resolution cross. Depending of the intent and data origin, the calibration can be antenna or baseline based, at scan level.

The calibration result is being notified by events, archived in the dataset and published through consumer interfaces in order to display it as a plot [QL[4]] or formatted plain text [TelCalSpy].

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[3] Wvr=Water Vapor Radiometer

[4] Quick Look

The Delay measurement is based on the following procedure:

- Perform a standard SFI interferometry measurement on bright quasar.[5]
- Use a change of phase with frequency (1nsec delay error cause 1 turn on phase at 1GHz).
- Need a reference antenna (the first one by default).
- Bandwidth, together with phase RMS, defines accuracy.
- Accuracy cannot be better than 0.5nSec in a 2GHz base-band.
- Delay is determined with an ambiguity of $\frac{1}{\Delta \nu}$ (inverse of channel width)
- Use TDM for sensitivity (better S/N), but use FDM in large delay error is expected.
- Adjust sub-scan duration to source flux

The last square fit method is used for obtaining the phase dependence. The result is the delay offset and its error[6].
The error result tells us "how much the phase values are correlated to the frequency values". So if this value is zero, this means that the phase/frequency are 100% correlated, in the appositive way if this value is 1, it means there is no correlation between phase and frequencies, which can also be interpreted as a loss of coherence issue.
The information presented below is an example of the output generated by the Calibration Delay.

=== New result: CAL_DELAY FULL_RESOLUTION_CROSS Scans: [1]
StartValid: 2014-05-08T00:46:51.168000 EndValid: 2014-06-08T00:46:51.168000 Duration 2678400.000s
Ant: DA43 Baseband: BB_1 Polar: X Band: ALMA_RB_03 RefAnt: DA42 Delay: -0.024ns (0.034)
Ant: DA43 Baseband: BB_1 Polar: Y Band: ALMA_RB_03 RefAnt: DA42 Delay: 0.028ns (0.032)
Ant: DA44 Baseband: BB_1 Polar: X Band: ALMA_RB_03 RefAnt: DA42 Delay: -0.006ns (0.026)
Ant: DA44 Baseband: BB_1 Polar: Y Band: ALMA_RB_03 RefAnt: DA42 Delay: 0.009ns (0.023)
Ant: DV01 Baseband: BB_1 Polar: X Band: ALMA_RB_03 RefAnt: DA42 Delay: 1.820ns (0.474)
Ant: DV01 Baseband: BB_1 Polar: Y Band: ALMA_RB_03 RefAnt: DA42 Delay: 3.656ns (0.498)
Ant: DV01 Baseband: BB_2 Polar: X Band: ALMA_RB_03 RefAnt: DA42 Delay: -9.051ns (0.506)
Ant: DV01 Baseband: BB_2 Polar: Y Band: ALMA_RB_03 RefAnt: DA42 Delay: 6.414ns (0.477)
Ant: DV01 Baseband: BB_3 Polar: X Band: ALMA_RB_03 RefAnt: DA42 Delay: 12.270ns (0.503)
Ant: DV01 Baseband: BB_3 Polar: Y Band: ALMA_RB_03 RefAnt: DA42 Delay: -4.595ns (0.472)
Ant: DV01 Baseband: BB_4 Polar: X Band: ALMA_RB_03 RefAnt: DA42 Delay: -2.156ns (0.489)
Ant: DV01 Baseband: BB_4 Polar: Y Band: ALMA_RB_03 RefAnt: DA42 Delay: 0.835ns (0.480)

In this example it is possible to observe that the reference antenna is the one named "DA42". The delay results are presented for each available base band signal (8 for each antenna). It is also possible to realize that antenna DV01 is showing larger phase errors (over 0.4), and it is also possible to observe that the granularity of this error is "all the base bands".

Finally it was discovered that the cause of this issue was a wrong configuration of the antenna delay value.

The results presented below belong to another case:

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Ant: DV01 Baseband: BB_1 Polar: X Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.937ns ( 0.014)
Ant: DV01 Baseband: BB_1 Polar: Y Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.947ns ( 0.010)
Ant: DV01 Baseband: BB_1 Polar: X Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.937ns ( 0.014)
Ant: DV01 Baseband: BB_1 Polar: Y Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.947ns ( 0.010)
Ant: DV01 Baseband: BB_2 Polar: X Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.940ns ( 0.010)
Ant: DV01 Baseband: BB_2 Polar: Y Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.942ns ( 0.008)
Ant: DV01 Baseband: BB_3 Polar: X Band: ALMA_RB_03 RefAnt: DA41 Delay:   -3.011ns ( 0.009)
Ant: DV01 Baseband: BB_3 Polar: Y Band: ALMA_RB_03 RefAnt: DA41 Delay:   -3.026ns ( 0.008)
Ant: DV01 Baseband: BB_4 Polar: X Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.931ns ( 0.018)
Ant: DV01 Baseband: BB_4 Polar: Y Band: ALMA_RB_03 RefAnt: DA41 Delay:    0.971ns ( 0.014)
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[5] During the delay calibration an unresolved source (or a spot) is observed, in that case the results of the visibilities (outcome of an interferometer) are amplitude and phase constant.
[6] Here after we will talk about error and phase rms indistinctly.

It is possible to observe that phase's errors are low, therefore the delay measurement is correct. However, they are not close to zero[7], so by using Table 1 we can figure out that the problem was caused by wrong antenna profile.

4. ERROR CASES AND DATA ANALYSIS

From the data provided by the Delay Calibration, two types of errors will be analyzed using this method:

1) Delay different than 0.
2) RMS greater than the expected value.

The first error to be analyzed is the one detected by a phase rms[8] value greater than the expected value, if one delay value is also associated to a big phase rms value, it will not be valid a measurements of the delay error, it must be considered as a loss coherence issue.

During the Delay measurement the delay value must be close to zero, if not we are facing:

a) Wrong delay Model.
b) Digital hardware is clocking upon the wrong phase.

Depending on the error granularity the suspicious faulty system can be found by using the flow chart presented in Figure 3.

If the phase rms is below the acceptable margins but the measured delays are away from the zero value, the possible causes can be found in synchronization problems, or a wrong configuration of the specific delay (those values are stored in a data base), Table 1 summarizes the possible delay errors and their causes.

Delay value	Possible problem	granularity
4 nSec	Wrong DGCK synchronization	All base band pairs
N x 16 nSec, N belongs to the integers	Wrong meta-frame delay adjustment	One base band pair
8 nsec	Wrong DRX synchronization	One base band pair
None of the above	Wrong antenna delay profile	Not defined

Table 1, Delay error cases, and their granularity.

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[7] Talking about close to zero is rather than a fuzzy concept. In this case we are considering close to a value if < 0.5nSec, see page 3

[8] rms = Root Mean Square.

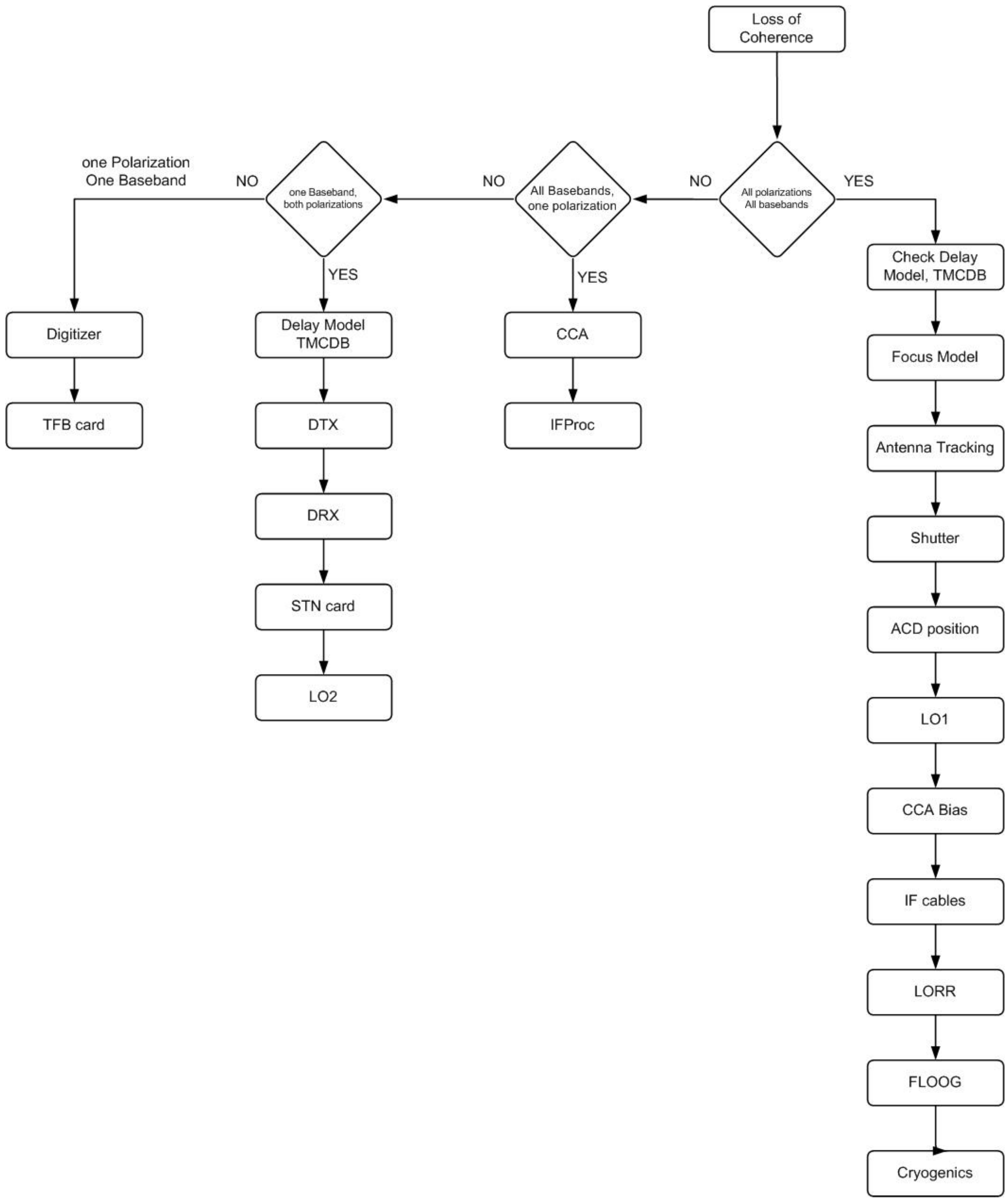

Figure 3, Flow chart which shows which sub-system can be examined for finding the cause of a loss of coherence problem.

5. IMPLEMENTATION

ALMASW provides python interfaces which one can interact with a particular subsystem or with the system as a whole, since ALMASW relies in ACS[2], python API allows to retrieve different data or results by exposing public component methods.

The interacion with TelCal relies on an event notification once the results are ready to be retrieved, sent by TelCal through the *telcalpublisher* channel by the *telcal_publisher* component to the consumers subscribed, these consumers reacts on these events by executing the exposed method by the component in order to retrieve the results and specific, in this particular case, reacting for the DelayReducedEvent.

The tool for analyzing the data produced by TelCal in the specific Delay Calibration was developed through the use of the Python language. This software tool is listening to the notification channel associated to the Delay Calibration, and it analyzes the obtained data once an event is reported by TelCal.

The analysis is based on detecting when the phase error is greater than 15 degrees rms[9]

6. FUTURE IMPROVMENTS

One possible improvement may be by adding the ability to get the phase rms for each sub-band (in FDM mode); having those values will make it possible to diagnose problems related to the correlator.

The current status of these tools only reports the suspicious sub-systems. An interesting path to follow is to the query the monitor points of the suspicious sub-system and, based on pre-established thresholds, alert which is the faulty hardware or configuration.

7. CONCLUSIONS

The original intention of the phase error value provided by the Delay Calibration was to serve a measurement of how precise the time delay is. In addition, that value could be also used for analyzing loss of coherence issues, since the delay values are presented in a way which is also consistent with how the data is split and processed by the ALMA instrument. That information can be used for finding which sub-system is introducing problems, or which hardware is not properly synchronized.

Considering the amount of antennas in the array for the ALMA telescope case, it is a cumbersome task try to find a loss of coherence problems while an observation is undergoing. Since the calibration is a task which must be done on a regular basis, using the TelCal for detecting loss of coherence issue and for indentifying the faulty hardware or configuration is an attractive approach.

8. REFERENCES

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[9] This is a typical value for a Band 3 at 300m base line observation,