Atacama
Large
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Array

Preliminary summary of ACA Testing Campaign

(2014 September)

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Preliminary summary of ACA Testing Campaign (2014 September)

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1. Overview

ACA Testing Campaign was done between September 23th and 30th for the verification of ACA Correlator software functions. Its main item was to verify on-line 4-bit linearity correction, which was improved on ALMA 2014.02. Another item was preliminary study for coming 3-bit linearity correction. This focused on the relation between input-power level to 3-bit digitizer and digitizer level histogram. Our data analysis is still on-going, but in our preliminary results, the revised 4-bit linearity correction works as designed. In the study of 3-bit digitizer, we have found that the relation looks to vary according to input-power level.

2. On-line 4-bit linearity correction (CSV-3133)

On-line 4-bit linearity correction is revised on ALMA 2014.02 so that the update interval of its correction factors is now integration/channel-average duration for full-resolution/channel-average data. This change is realized by software update and nothing is changed in correlator hardware. In the previous version, the interval was correlator calibration, and there could remain non-linearity due to the 4-bit re-quantizer if signal-level varied between the calibrations (e.g. PRTSIR-656).

We verified the revised correction according to the following steps:

Step1. Algorithm verification using ACA Correlator simulator (CSV-3134)

We verified the algorithm of the 4-bit linearity correction using computational simulation.

Step2. On-line correction verification (CSV-3135 and CSV-3136)

On-line 4-bit linearity correction was tested by comparing its products with its off-line correction products, whose correction algorithm was verified in Step 1.

Step3. Linearity check between input and output power of 4-bit re-quantization (CSV-3138)

We also tested the linearity between input and output power of 4-bit re-quantization under the on-line 4-bit linearity correction.

2.1. Algorithm verification using ACA Correlator simulator (CSV-3134)

First, we verified the correction algorithm beforehand using ACA Correlator simulator, which could calculate bit-accurate results of ACA Correlator processing. Known 3-bit data were input to the simulator and re-quantized by 4-bit with two different input-levels employing an optimized scaling-factor every channel and a constant scaling-factor over channels. Then, 4-bit linearity correction was applied to output spectra and compared with original inputs. Figure 1 shows the comparison results where original and 4-bit quantized spectra agree well with each other after the 4-bit linearity correction.

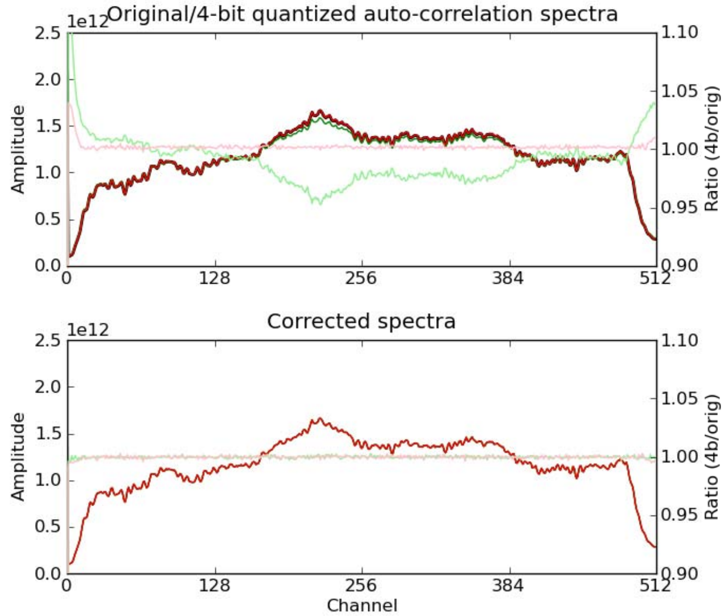

Figure 1 Computational simulation of the 4-bit linearity correction
(Upper) auto-correlation spectra with 4-bit re-quantization (red and green lines) and original spectra (black line). Red and green lines correspond to 4-bit re-quantization with optimized scaling-factors and a constant scaling factor, respectively. Their ratios to original spectra are shown by pink (= red / black) line and light green (= green / black) line. (Lower) auto-correlation spectra corrected by 4-bit linearity correction (red and green lines) and original spectra (black line). These three spectra are well overlapped, indicating that they are well consistent. This can be also confirmed by their ratios, which are pink (= red / black) line and light green (= green / black) line.

2.2. On-line correction verification (CSV-3135 and CSV-3136)

Next, we tested on-line 4-bit linearity correction by comparing on-line and off-line correction products, because the off-line correction was already confirmed in Step 1. In the verification tests, internal signal-level was optimized at 0 dB corresponding to +2.4 dBm in an absolute value and then, the level was increased from -7 dB to +3 dB by changing attenuator setting within a subscan. During it, auto-correlation spectra toward the south pole were continuously taken with/without the on-line correction. Then, we applied the off-line correction to the spectra without the on-line correction. The comparison results between on-line and off-line corrections are shown in Figure 2 and Figure 3. Good agreement between them can be seen in these plots.

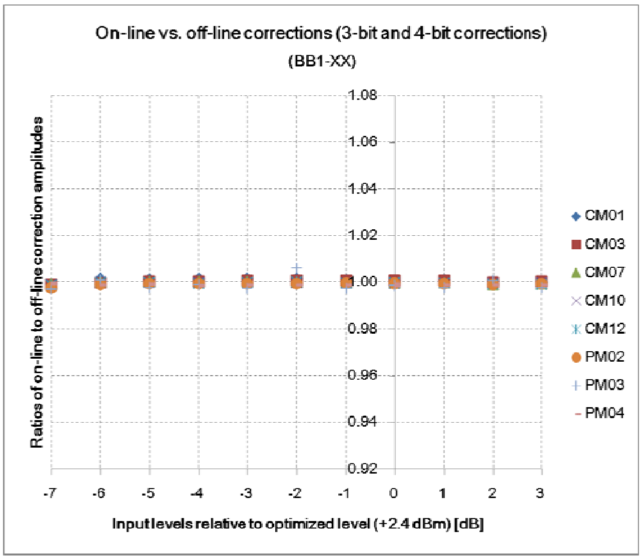

Figure 2 Channel-average amplitude ratios of on-line to off-line corrected spectra

Each symbol indicate channel-average amplitude ratios of on-line and off-line corrected spectra of BB1-XX of each antenna. Correlator calibration was carried out at 0 dB, corresponding to +2.4 dBm. Their differences between on-line and off-line corrected spectra are less than ±1%.

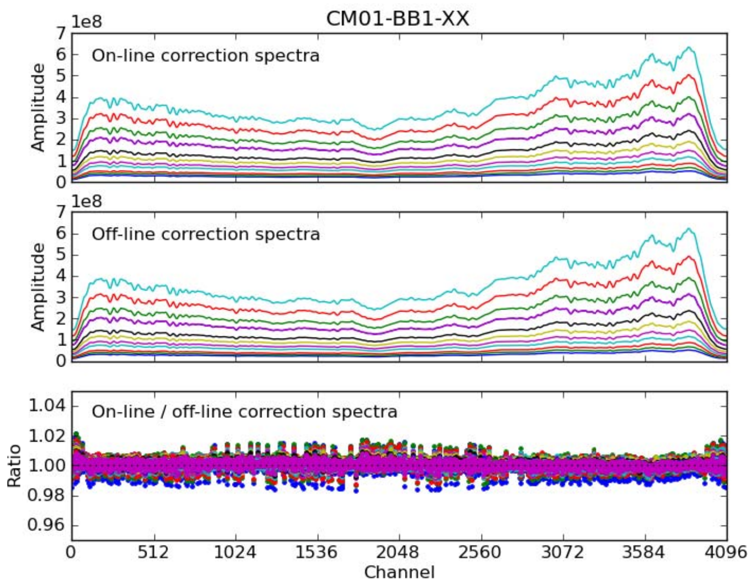

Figure 3 On-line and off-line corrected spectra and their ratios

(Upper) Auto-correlation spectra with on-line correction at CM01-BB1-XX. Different colors indicate different input signal-levels (-7 dB to +3 dB by 1 dB step). (Middle) Auto-correlation spectra with off-line correction. The colors are same as those of the upper plot. (Lower) The ratio of on-line to off-line correction spectra. They are close to 1.0 and the differences are roughly within ±1%.

2.3. Linearity check between input and output power of 4-bit re-quantization (CSV-3138)

Finally, simple variance of 3-bit digitizer level histogram was compared with auto-correlation amplitude, to which no 3-bit linearity correction was applied. They correspond to input and output power of the 4-bit re-quantization, respectively. Figure 4 shows good linearity between them.

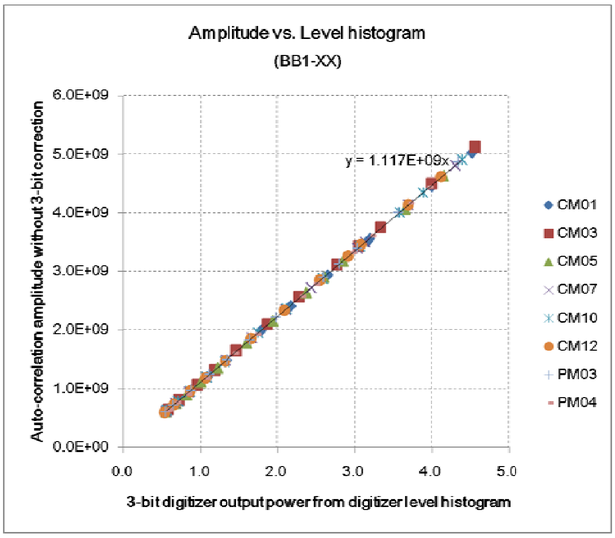

Figure 4 Auto-correlation amplitude vs. 3-bit digitizer output power

Auto-correlation amplitudes of channel average data without 3-bit linearity correction are plotted against 3-bit digitizer output power-levels, which are simple variance of digitizer level histograms.

3. Input-power level estimated from digitizer level histogram (CSV-2311)

We also studied the relation between input-power level to 3-bit digitizer and digitizer level histogram of 3-bit digitized signals. ACA Correlator compensates for the non-linearity of 3-bit digitizer using the relation, which is derived assuming ideal 3-bit digitizer. However, recent issues (e.g. PRTSIR-656 and Tsys differences between BLC-TDM and ACA by several percent reported in TP/ACA non-linearity Tiger Team meeting) suggest that there seem to be non-negligible errors in the assumption of the correction. For its investigation, we measured digitizer level histograms with ACA Correlator and baseband power levels with baseband power detectors by varying input-power level to 3-bit digitizer in the range of -7 dB to +3 dB by 1 dB step. From our quick analysis of obtained data, we got the following preliminary results.

1. Linear relation can be roughly seen between the level histogram and the baseband power. However, taking a close look at them, there looks to be departures from the linear regression. One possible explanation is that threshold voltages of the 3-bit digitizers were not uniformly spaced or variable as a function of input power level. Or the probability density distribution of the input analog signal did not follow the normal distribution.

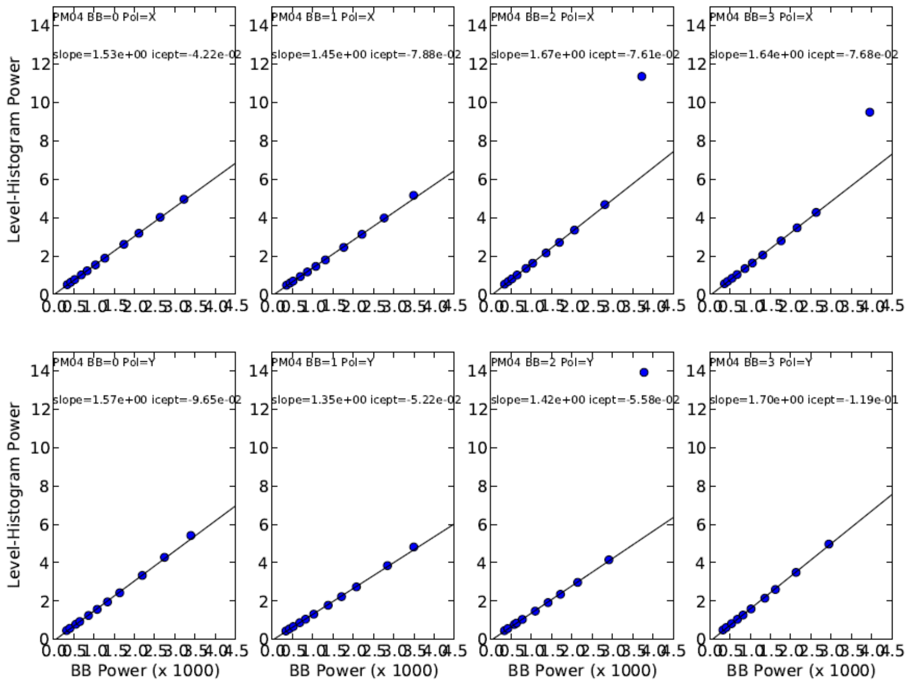

Figure 2 of "ADCLevel20140927.pdf" in CSV-2311

Comparison of the total power measurements with baseband detector (horizontal axis) and digitizer level histogram (vertical axis). Linear regression was applied except the highest power point to determine the slope and the intercept.

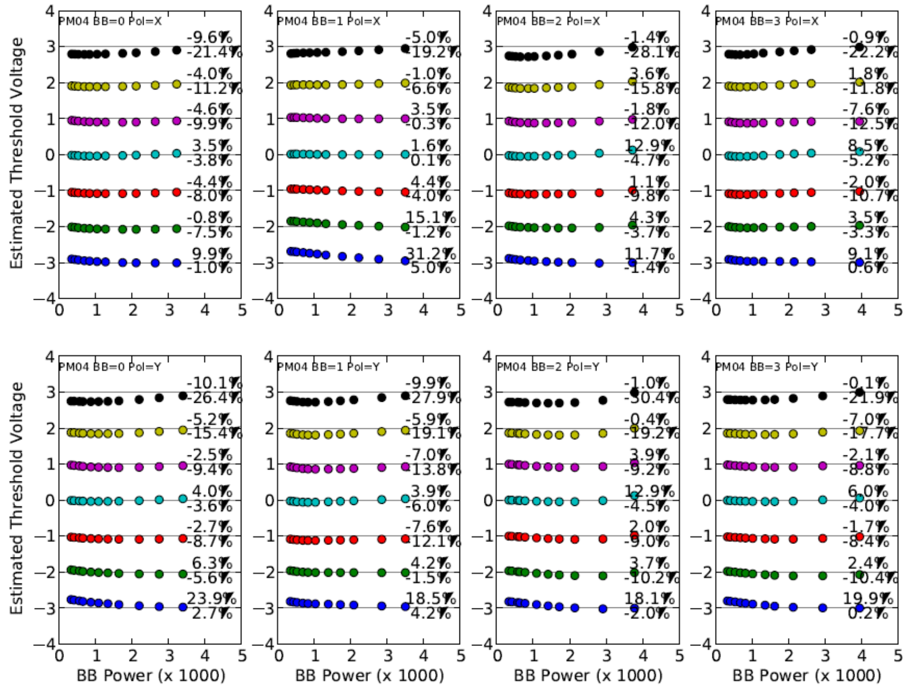

Figure 5 of "ADCLevel20140927.pdf" in CSV-2311

Estimated threshold voltages of 3-bit quantization in the digitizer as a function of input power level. If the thresholds were constant, uniformly spaced, and the probability density distribution of the input voltage followed the normal distribution (ideal case), the estimated thresholds would lie on the integer values regardless the power level. Departures from the ideal case are shown in percentile.

2. The accuracy of the threshold voltages is good for 2-bit (4-level) but insufficient for 3-bit (8-level) quantization.

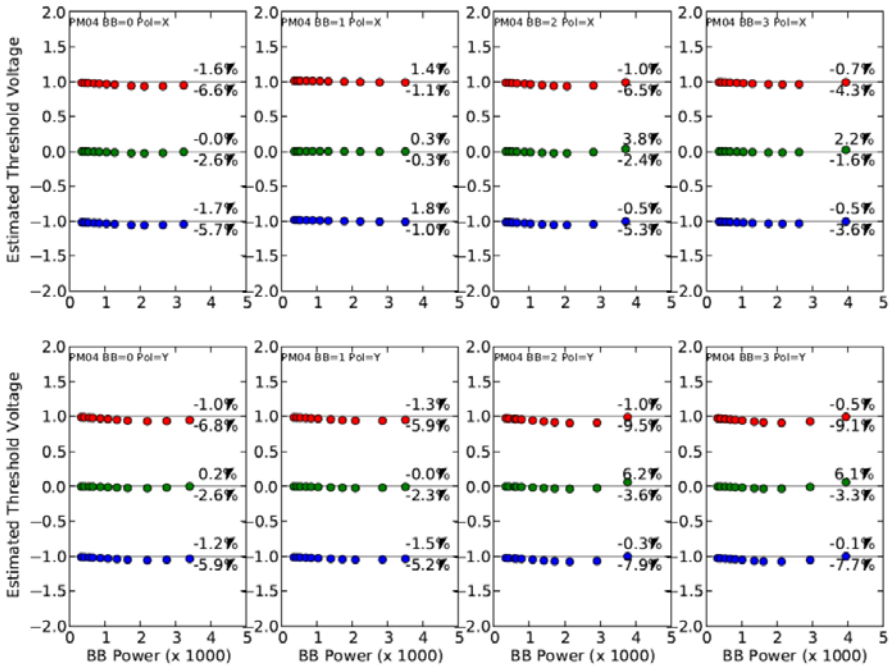

Figure 7 of "ADCLevel20140927.pdf" in CSV-2311

Estimated threshold voltages for 2-bit quantization. The same level-histogram data with Figure 5 were used to produce 2-bit quantized samples by combining pairs of adjacent levels. Since current BLC-TDM employs 2-bit quantization, its linearity will be less affected.

3. The error in threshold voltages can cause significant non-linearity of power measurements with the ACA Correlator which uses 3-bit quantized signals.

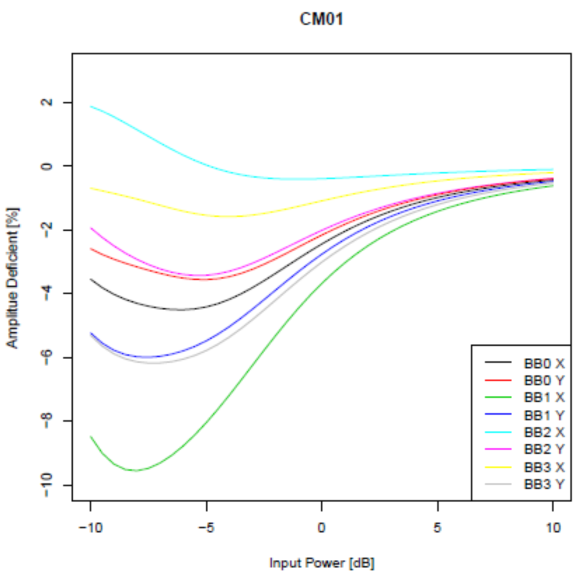

Figure 2 of "ADCLevel20140928.pdf" in CSV-2311

Systematic errors of digital power measurements as a function of input analog power level. The optimal input level stands for 0 dB. Each estimated threshold voltage is used to evaluate the systematic errors.

We need to investigate stability of the threshold-voltage behavior and consider its correction way for the further improvement of 3-bit quantization correction.

4. Summary and additional work plans

4.1. On-line 4-bit linearity correction and additional tests for it

From our quick analysis so far, output spectra with the revised on-line 4-bit linearity correction are consistent with those from the off-line correction, which is already verified using computational simulation. This consistency is confirmed in varying signal-level within a subscan. Thus, we think that the revised on-line 4-bit linearity correction works as designed, although they are still preliminary results from a part of obtained data. We are now looking at remaining data in order to make sure that the 4-bit correction widely works. For the purpose, enough data were already taken, and further data are not required.

4.2. 3-bit digitizer issue

About the issue of variable threshold voltages of 3-bit digitizer, it is necessary to repeat the measurement done in CSV-2311 in order to pursue its behaviors and establish its correction method. In addition, it may be better to measure in other receiver bands than band 3, although we think the issue is specific to each digitizer. We plan to do these additional measurements in Kameno-san's regular OSF shift. We are also considering similar measurements using noise source and power meter, which are calibrated well.

Related tickets

- CSV-3133 ACACORR: On-line 4-bit linearity correction of ACA Correlator
- CSV-3134 ACACORR: Simulation of the 4-bit linearity correction
- CSV-3135 ACACORR: Comparison with/without the new 4-bit linearity correction
- CSV-3136 ACACORR: Variable signal-levels in a subscan
- CSV-3138 ACACORR: Linearity measurement between digitizer level histogram and auto-correlation amplitude 3-bit correction task
- CSV-2311 Measure non-linearity between signal levels input to 3-bit digitizer and digitizer level histogram taken with the ACA Correlator

References

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- Kameno, S., Kamazaki, T., "Non-uniformity of the Digitizer Threshold Voltages and Impact to Amplitude Linearity (CSV-2311)", "ADCLevel20140928.pdf" in CSV-2311
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- Kameno, S., Kamazaki, T., “Linearity of power measurements in the ACA correlator (CSV-3638), “ADCLevel20141016.pdf” in CSV-3638