TITLE:	**REBA calibration and verification during the LFI CPV phase**		
DOC. TYPE:	Test report		
PROJECT REF.:	PL-LFI-PST-RP-072	PAGE:	1 of 19
ISSUE/REV.:	1.1	DATE:	October 8, 2009

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CHANGE RECORD

Issue	Date	Sheet	Description of change	Release
1.0	8th October, 2009	All	First issue of document	0.1
1.1	15th December, 2009	All	Logo updated, explicit author list	0.1

DISTRIBUTION LIST

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Contents

Abstract

In this document we present the results of the LFI REBA compressor calibration and verification performed during the CPV phase. Due to the need of changing the tuning of the LDI channels in the middle of the CPV phase, we were required to perform the calibration/verification tests on the REBA twice (ODs 64-67 and ODs 75-77). This report discusses the results of both tests.

1 Introduction

1.1 Purpose and Scope

The LFI SPU is a module of the REBA whose main purpose is to compress the scientific data acquired by the radiometers and digitized by the DAE. The data compression is a crucial feature of Planck, since its angular resolution and high data acquisition frequency forbid the transmission to Earth of the full data acquired during the mission.

The compressor uses a mix of high-level techniques that reduce the data size by discarding information that is either not scientifically relevant (e.g. at very high frequencies) or dominated by the intrinsic radiometric noise. It is therefore extremely important to calibrate the SPU so that no scientifically relevant information is discarded during the compression.

Each calibration test is made by two parts:

1. The first part requires the acquisition mode to be set to AVR1 (uncompressed acquisition) for 45 minutes per detector. The data acquired during the first part are used to find 44 sets of parameters (one per each detector) for the REBA compressor.

2. After the REBA has been programmed with these parameters, a second acquisition in compressed mode (COM5) of 22 h is done. The performances of the compressor are derived from these data and compared with the expectations.

The purpose of the test is to produce a set of 44 parameters (one per each LFI channel) that allows the instrument to compress the data with a compression ratio $c_r \approx 2.4$ and a quantization error which is the lowest possible ([AD2] traduces this requirement stating that ϵ_q/σ must be less than 0.1 for the differenced and the total-power signals).

This document contains the results of the calibration tests performed on the REBA compressor during the LFI CPV phase. The calibration of the compressor had to be done twice, the first one on July, 16th 2009 and the second one on July, 27th 2009. This was needed because a number of evidences showed that the ACA biases needed further tuning after the first calibration. In this document we describe the results of both calibrations. The second calibration produced the parameters used during the First Light Survey (FLS) and the subsequent "nominal" acquisition that is still ongoing.

1.2 Test Configuration

The software used for the analysis has been Pegaso 0.13.0 (release date: 2009/07/31). We have also used a beta version of OCA2 (yet to be released) for the first calibration of the REBA (OD64). The LFI personnel involved during the test is listed in the following table:

Role	Name	Institute	E-mail
AIV Manager	A. Gregorio	UniTS	anna.gregorio@ts.infn.it
Calibration S.	A. Mennella	UniMI	daniele.mennella@fisica.unimi.it
Instrument S.	M. Bersanelli	UniMI	marco.bersanelli@fisica.unimi.it
IOT	M. Tomasi	UniMI	maurizio.tomasi@unimi.it
IOT	M. Maris	OATS	maris@oats.inaf.it

2 Applicable and Reference Documents

Reference Documents

[RD1] Luca Stringhetti. Tuning of REBA Scientific Parameters. Technical Report PL-LFI-PST-PT-024, INAF/IASF Bologna, November 2007.

Applicable Documents

[AD1] A. Gregorio, M. Miccolis, L. Stringhetti, and A. Zacchei. Planck LFI User Manual. Technical Report PL-LFI-PST-MA-001, University of Trieste, June 2007.

[AD2] M. Maris and M. Tomasi. Metrics for the quantization erroranddefinitionofa“fictious” σ/q. Technical Report PL-LFI-OAT-TN-055, OAT, August 2008.

[AD3] M. Tomasi and M. Maris. CSL REBA Calibration Results and Recommendations for the Flight Calibration. Technical Report PL-LFI-OAT-TN-062, OAT, July 2009.

[AD4] M. Tomasi, M. Maris, and A. Mennella. REBA calibration and verification. Technical Report PL-LFI-PST-PR-061, UniMi/UniTs, August 2008.

3 Description of the Tests

3.1 First phase (acquisition in AVR1 mode)

The scientific output of the radiometers is acquired in four consecutive tests in order not to overflow the telemetry budget. Each set (and consequently each `TUN` file saved by the TQL) contains the same number of radiometric channels (2×30 GHz, 3×44 GHz and 6×70 GHz). This allows to keep the same telemetry amount in every test. See table 2 for the detailed distribution of the channels in each set. The scientific telemetry has been acquired in Type1 with nominal `N_AVERAGE` settings.

The following table lists the times of each set for the two calibration tests (both in UTC and SCET units, the day was July, 16th 2009 OD64 for the first four sets and July, 27th 2009 OD75 for the last ones):

Temperatures in the focal plane and the back-end units were stable during the two calibration tests. The HFI 4 K Cernox temperature sensor showed peak-to-peak fluctuations of the order of 2 mK, therefore well within the requisite.

3.1.1 Procedure/Test Sequence

See [RD1] and [AD1].

		Start	End
OD64	Set #1	1 626 447 600 (15:00z)	1 626 450 300 (15:45z)
	Set #2	1 626 450 300 (15:45z)	1 626 453 000 (16:30z)
	Set #3	1 626 453 000 (16:30z)	1 626 455 700 (17:15z)
	Set #4	1 626 455 700 (17:15z)	1 626 458 400 (18:00z)
OD75	Set #1	1 627 394 412 (14:00z)	1 627 397 110 (14:45z)
	Set #2	1 627 397 113 (14:45z)	1 627 400 812 (15:30z)
	Set #3	1 627 400 814 (15:30z)	1 627 403 513 (16:15z)
	Set #4	1 627 403 515 (16:15z)	1 627 406 204 (17:00z)

Table 1: Time ranges for the two REBA calibration tests.

3.1.2 Discussion of the Results

The only objective of this step was to collect data for the two REBA calibration tests. The biases and DAE settings (offset, gain) used during the tests are reported in table 6 (OD64) and table 7 (OD75) at pages 13 and 14.

	OD64	OD75
No unexpected event packets	PASSED	PASSED
Data collected and saved on the LIFE machine	PASSED	PASSED

3.2 Data Analysis and Production of the Scientific Parameter Table

3.2.1 Procedure/Test Sequence for the First Calibration

The analysis of the first calibration test was performed by M. Tomasi and M. Maris using a number of different approaches. The motivation for such complex analysis was in the fact that the CSL test described in [AD4] showed unusually high level of quantization in the total power signal. As [AD3] reports, such high errors are likely to induce systematics in the determination of r (the *gain modulation factor*), necessary to study the scientific content of the radiometric signal.

The calibration strategies followed to extract the best calibration can be divided into a number of groups:

- A first group tries to optimize the differenced[1] signal $x_{\mathrm{sky}} - r \times x_{\mathrm{ref}}$;
- Another strategy is to optimize the total-power signal x_{sky} (this usually lead to an optimization of x_{ref} as well);
- A third strategy is to optimize both the differenced and the total-power signal, trying to make them as much similar as possible;
- Finally, a tentative optimization that considers also the error on the determination of the r parameter has been tried by M. Maris on a beta version of OCA2 (still to be released).

The final calibration has been produced by comparing one by one the eight calibration tables and choosing the best configuration per each detector. This was decided by considering both the quantization error on the total power signals (sky/reference) and on the difference. We also considered the impact of the quantization on the estimation of the gain modulation factor r.

[1] A low quantization in the differenced signal does not necessarily imply a low quantization of x_{sky} and x_{ref} as well. Usually it is the contrary: the smaller the quantization of the differenced signal, the greater (up to ten times) the quantization of the total power signal. It is the correlation between the quantization of x_{sky} and x_{ref} that helps in keeping the quantization of the differenced signal low.

	RCA	Channel			
Set #1 (45')	#27	00	01		
	#24		01	10	11
	#21	00	01	10	11
	#22	00	01		
Set #2 (45')	#27			10	11
	#24	00			
	#22			10	11
	#23	00	01	10	11
	#25	00	01		
Set #3 (45')	#25			10	11
	#28	00	01		
	#20	00	01	10	11
	#19	00	01		
Set #4 (45')	#28			10	11
	#19			10	11
	#18	00	01	10	11
	#26		01	10	11

Table 2: Order of acquisition for the 44 LFI channels during the first part of the REBA tuning. This ordering applied both to the first and second calibration done during CPV, and it is the same as the procedure used in CSL. Each set is acquired in AVR1 mode for 45 minutes.

3.2.2 Procedure/Test Sequence for the Second Calibration

Due to the shorter time available for data analysis during the second calibration (less than 24 hours), we decided to apply an automatic procedure to extract the best calibration values for the REBA from the AVR1 data. This procedure uses the so-called `sky` strategy implemented by OCA2, which follows these guidelines:

1. Each channel must be able to achieve a compression rate roughly equal to 2.4 (i.e. configurations leading to a worse or a better compression rate are discarded[2]);

2. For all the possible configurations that satisfy the previous point ($c_r = 2.4$), the one with the lowest quantization error in the *sky* signal is preferred.

This strategy has several advantages over the standard one (i.e. optimizing the quantization in the *differenced* signal):

- Although this is not true in general, usually a good quantization in the sky signal implies a good quantization in the reference signal as well;

- It allows to get a good quantization in the total power signal, because this helps in the reconstruction of the gain modulation factor r;

- A good quantization in the total power signals usually do not produce a very high quantization in the difference[3].

[2] This because a better compression rate always implies an higher quantization error. In fact, the ideal situation is *not to compress* data in order to avoid discarding any information.

[3] Note however that optimizing the quantization in the difference directly – as it has been the baseline in CSL

We used some tricks to improve the quantization error in the signals – refer to the next section for the details.

3.2.3 Analysis Codes

The first three strategies listed in section 3.2.1 can be implemented using the following IDL script and changing the value of the `strategy` variable accordingly:

```
strategy = 'sky'  ;; Alternatives: 'diff', 'diff_sky'
result1 = oca2 ('pegaso', [1626447600d, 1626450300d], $
                [2700, 2701, 2100, 2101, 2110, 2111, $
                 2200, 2201, 2401, 2410, 2411], $
                strategy = strategy, /normalize_rms)

result2 = oca2 ('pegaso', [1626450300d, 1626453000d], $
                [2710, 2711, 2400, 2210, 2211, 2300, $
                 2301, 2310, 2311, 2500, 2501], $
                strategy = strategy, /normalize_rms)

result3 = oca2 ('pegaso', [1626453000d, 1626455700d], $
                [2510, 2511, 2800, 2801, 2000, 2001, $
                 2010, 2011, 1900, 1901, 2600], $
                strategy = strategy, /normalize_rms)

result4 = oca2 ('pegaso', [1626455700d, 1626458400d], $
                [2810, 2811, 1910, 1911, 1800, 1801, $
                 1810, 1811, 2601, 2610, 2611], $
                strategy = strategy, /normalize_rms)

results = [result1, result2, result3, result4]
results = results[sort (results.channel)]
r = oca2_write_report ('pegaso', results)

;; Print the best REBA parameters
for i = 0, n_elements (results) - 1 do $
  print, format = '(%"%d %8.5f %8.5f %8.2f %8.5f")', $
    results[i].channel, $
    results[i].best_params.r1, $
    results[i].best_params.r2, $
    results[i].best_params.offset, $
    results[i].best_params.second_quant

;; Print compression ratios, quantization errors and data rates
for i = 0, n_elements (results) - 1 do $
  print, format = '(%"%d %5.2f %6.4f %6.4f %6.4f %8.2f")', $
    results[i].channel, $
```

– produces larger errors in the total power signals but produces much better results in the differenced signal. This is explained by the fact that total power quantization errors are highly correlated and therefore they cancel in the difference. The old strategy is usually able to produce quantization errors in the difference that are lower by a factor of ~ 2 with respect to this new strategy.

```
    results[i].verification.cr, $
    results[i].verification.qe_over_rms_sky, $
    results[i].verification.qe_over_rms_ref, $
    results[i].verification.qe_over_rms_dif, $
    results[i].verification.compressed_data_rate
```

Note the use of the `normalize_rms` keyword in the call to `oca2`. This is a new keyword introduced in Pegaso 0.12.0 to remove the dipole from the sky and differenced signals before calculating the signal RMS (σ). This allows to correctly compare the quantization error ϵ_q/σ for the sky, reference and differenced signals.

The procedure for the second calibration is simply the same code used above with `strategy = 'sky'` and with the time ranges used in the four calls to `oca2` set to the appropriate values taken from table 1. The reason for this different approach was due to the shorter time available for the calibration (less than 24 hours, to be compared with the 48 hours available for the analysis of OD64 data).

However, at the end of each call to `oca2` we called `oca2_refine_results` in order to explore a narrower region in the $r_1 \times r_2$ space whose center is the best pair found by `oca2` itself. We then used `oca2_combine_results` to pick up the best choice between the configuration found in the first call to `oca2` and in the new one found by `oca2_refine_results`. Each call to `oca2` was therefore written in this way:

```
rough_result   = oca2 ('pegaso', ...)
refined_result = oca2_refine_results ('pegaso', rough_result)
best_result    = oca2_combine_results (rough_result, refined_result)
```

and `best_result` is the one used to produce the calibration table. The criteria used by the function `oca2_combine_results` to pick the best configuration are (in order of importance):

1. Prefer the configuration which shows a lower quantization in the differenced signal;
2. Prefer the configuration which shows a lower quantization in the total-power signal;
3. Prefer the configuration which requires less bandwitdh.

If no configuration win any of the above criteria, then `oca2_combine_results` chooses the configuration from its first argument[4] (`rough_result`).

3.2.4 Results and Conclusions

	OD64	OD75
Average compression rate ≥ 2.4	PASSED	PASSED
$(\epsilon_q/\sigma \leq 1)_{\mathrm{diff}}$ for every channel	PASSED	PASSED
No saturations found in any channel	PASSED	PASSED

The results of the first calibration (OD64) are shown in table 3, while the results of the second one (OD75) – the one currently used – are reported in table 4. Plots of the compression ratio, data rate and quantization errors are shown in figures 1, 2 and 3. These plots show the results of the verification tests as well (dark bars); for further information, refer to the following sections.

[4] Of course this is arbitrary: using the one from the second argument (`refined_result`) would be equally fine.

Ch.	c_r	$\epsilon_q/\sigma_{\mathrm{sky}}$	$\epsilon_q/\sigma_{\mathrm{ref}}$	$\epsilon_q/\sigma_{\mathrm{dif}}$	Data rate [bps]
1800	2.40	0.0202	0.0096	0.1576	1102.85
1801	2.40	0.0873	0.0297	0.0430	1101.45
1810	2.40	0.0488	0.0326	0.0531	1098.65
1811	2.40	0.1228	0.0703	0.0373	1100.93
1900	2.38	0.0489	0.0341	0.0488	1110.15
1901	2.38	0.0552	0.0345	0.0433	1108.36
1910	2.39	0.0533	0.0403	0.0447	1104.94
1911	2.38	0.0501	0.0378	0.0464	1107.75
2000	2.36	0.0549	0.0400	0.0412	1118.39
2001	2.36	0.0571	0.0384	0.0407	1117.48
2010	2.40	0.0512	0.0340	0.0488	1102.89
2011	2.40	0.0529	0.0352	0.0480	1101.81
2100	2.40	0.0525	0.0269	0.0569	1102.57
2101	2.40	0.0499	0.0262	0.0579	1104.09
2110	2.40	0.1519	0.0706	0.0369	1102.26
2111	2.40	0.0562	0.0312	0.0564	1100.43
2200	2.38	0.0517	0.0347	0.0492	1112.53
2201	2.38	0.0531	0.0346	0.0491	1110.67
2210	2.36	0.0327	0.0272	0.0768	1116.63
2211	2.35	0.0316	0.0269	0.0800	1121.22
2300	2.38	0.0469	0.0334	0.0491	1109.75
2301	2.37	0.0430	0.0327	0.0522	1113.97
2310	2.38	0.0397	0.0296	0.0581	1110.39
2311	2.36	0.0391	0.0306	0.0538	1117.27
2400	2.40	0.1248	0.1125	0.0370	650.84
2401	2.40	0.1456	0.1206	0.0367	651.20
2410	2.40	0.1409	0.1095	0.0374	651.57
2411	2.40	0.1355	0.1058	0.0378	651.80
2500	2.44	0.0501	0.0446	0.0565	640.14
2501	2.44	0.0523	0.0425	0.0524	640.63
2510	2.40	0.1014	0.0829	0.0374	650.96
2511	2.40	0.0875	0.0611	0.0372	651.95
2600	2.40	0.0964	0.0826	0.0380	650.64
2601	2.40	0.1125	0.0901	0.0370	649.49
2610	2.40	0.0984	0.0865	0.0374	651.22
2611	2.40	0.1106	0.0900	0.0464	650.60
2700	2.39	0.1269	0.1229	0.0396	456.28
2701	2.40	0.0702	0.0468	0.0598	455.43
2710	2.40	0.1230	0.1266	0.0384	455.35
2711	2.40	0.0890	0.0886	0.0399	455.16
2800	2.41	0.0643	0.0484	0.0477	452.95
2801	2.40	0.0645	0.0496	0.0476	454.93
2810	2.40	0.1303	0.1222	0.0385	455.12
2811	2.40	0.1315	0.1320	0.0385	454.80

Table 3: Forecasts of the first calibration run. These parameters are the result of the simulations done with OCA2 during the first phase (calibration) of the first REBA tuning (OD64). The total COM5 data rate was 38 028 bit/s.

Ch.	c_r	$\epsilon_q/\sigma_{\text{sky}}$	$\epsilon_q/\sigma_{\text{ref}}$	$\epsilon_q/\sigma_{\text{dif}}$	**Data rate [bps]**
1800	2.36	0.0328	0.0252	0.0694	1120.452
1801	2.38	0.0338	0.0255	0.0751	1114.205
1810	2.36	0.0394	0.0303	0.0419	1120.726
1811	2.39	0.0444	0.0315	0.0522	1110.492
1900	2.38	0.0505	0.0318	0.0487	1111.321
1901	2.38	0.0579	0.0298	0.0408	1111.843
1910	2.37	0.0478	0.0384	0.0444	1116.942
1911	2.37	0.0458	0.0384	0.0489	1116.180
2000	2.36	0.0527	0.0346	0.0411	1121.387
2001	2.35	0.0532	0.0367	0.0410	1124.873
2010	2.37	0.0481	0.0370	0.0469	1118.127
2011	2.35	0.0480	0.0370	0.0432	1125.904
2100	2.38	0.0466	0.0319	0.0444	1111.377
2101	2.40	0.0463	0.0300	0.0566	1102.517
2110	2.39	0.0452	0.0346	0.0508	1110.618
2111	2.38	0.0460	0.0347	0.0514	1113.168
2200	2.42	0.0479	0.0337	0.0593	1097.263
2201	2.42	0.0489	0.0349	0.0551	1097.643
2210	2.41	0.0354	0.0284	0.0784	1101.955
2211	2.40	0.0348	0.0274	0.0795	1106.093
2300	2.36	0.0391	0.0341	0.0592	1121.624
2301	2.36	0.0387	0.0331	0.0483	1123.747
2310	2.39	0.0418	0.0249	0.0539	1110.207
2311	2.41	0.0430	0.0265	0.0660	1101.303
2400	2.44	0.0902	0.0884	0.0528	641.233
2401	2.45	0.0917	0.0923	0.0462	640.213
2410	2.44	0.0946	0.0938	0.0658	641.981
2411	2.44	0.1001	0.1155	0.0783	640.996
2500	2.45	0.1136	0.1266	0.0712	639.419
2501	2.45	0.1106	0.1338	0.0769	639.632
2510	2.45	0.1016	0.1025	0.0624	640.806
2511	2.43	0.1107	0.1153	0.0875	644.624
2600	2.45	0.0956	0.1083	0.0613	639.300
2601	2.45	0.1141	0.1193	0.0706	638.572
2610	2.45	0.0890	0.0960	0.0525	639.405
2611	2.45	0.1226	0.1495	0.0866	639.810
2700	2.39	0.0570	0.0444	0.0521	458.010
2701	2.38	0.0568	0.0451	0.0523	459.102
2710	2.39	0.0567	0.0443	0.0508	457.829
2711	2.39	0.0593	0.0462	0.0520	457.129
2800	2.40	0.0563	0.0482	0.0474	456.442
2801	2.38	0.0556	0.0473	0.0458	460.034
2810	2.40	0.0597	0.0468	0.0479	456.080
2811	2.41	0.0613	0.0468	0.0477	454.355

Table 4: Forecasts of the second calibration run. These parameters are the result of the simulations done with OCA2 during the first phase (calibration) of the second REBA tuning (OD75). The total COM5 data rate was 38 055 bit/s.

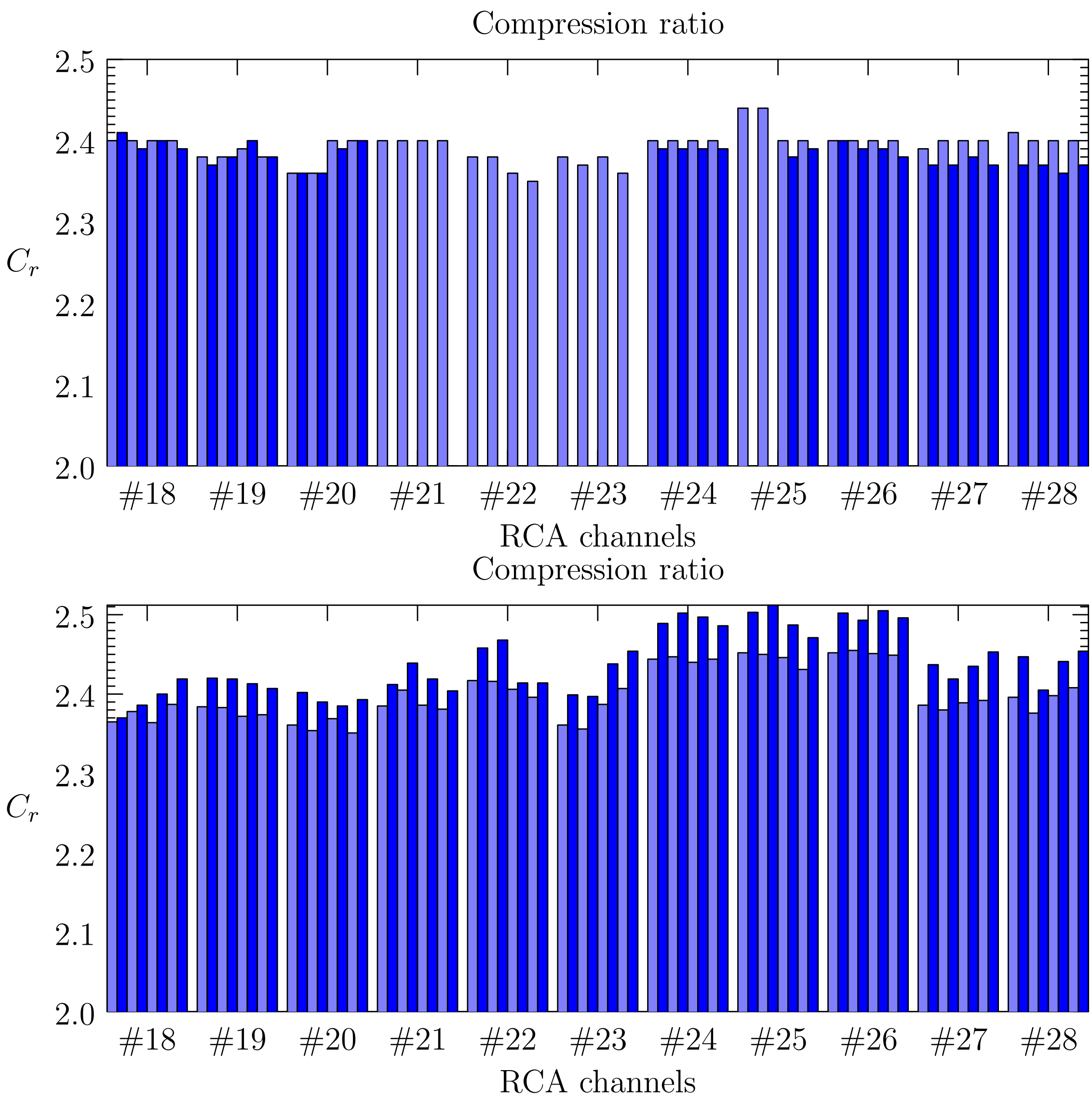

Figure 1: Compression ratio for the first (OD64, top) and second (OD75, bottom) REBA tuning tests. Light bars are the results of the simulations done with OCA2 using the data from the first (calibration) tuning phase. Dark bars are the values effectively measured during the second (verification) tuning phase.

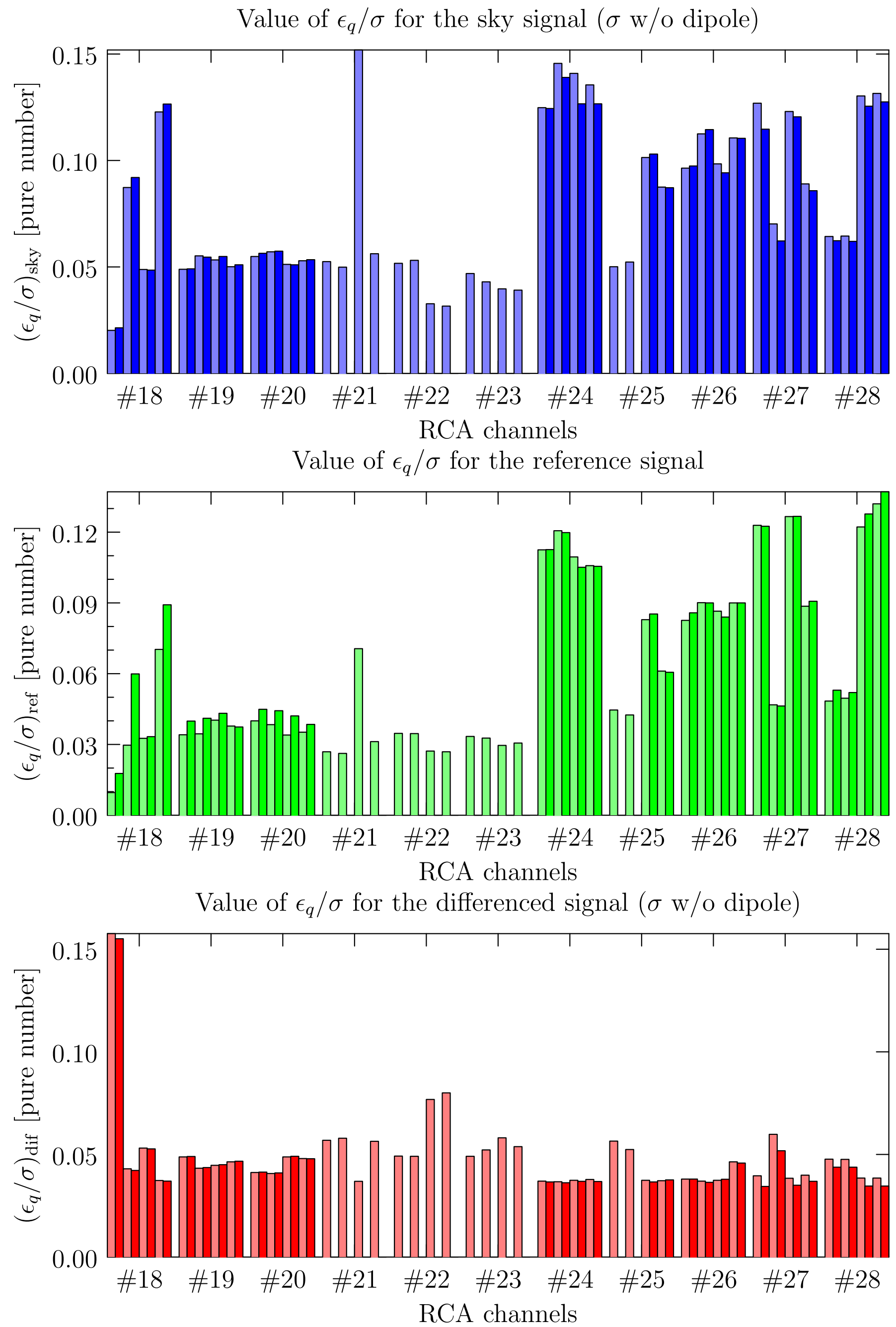

Figure 2: Ratio between the quantization error and the intrinsic RMS of the sky, reference and differenced signals for the first REBA calibration (light bars) and verification (dark bars) tests.

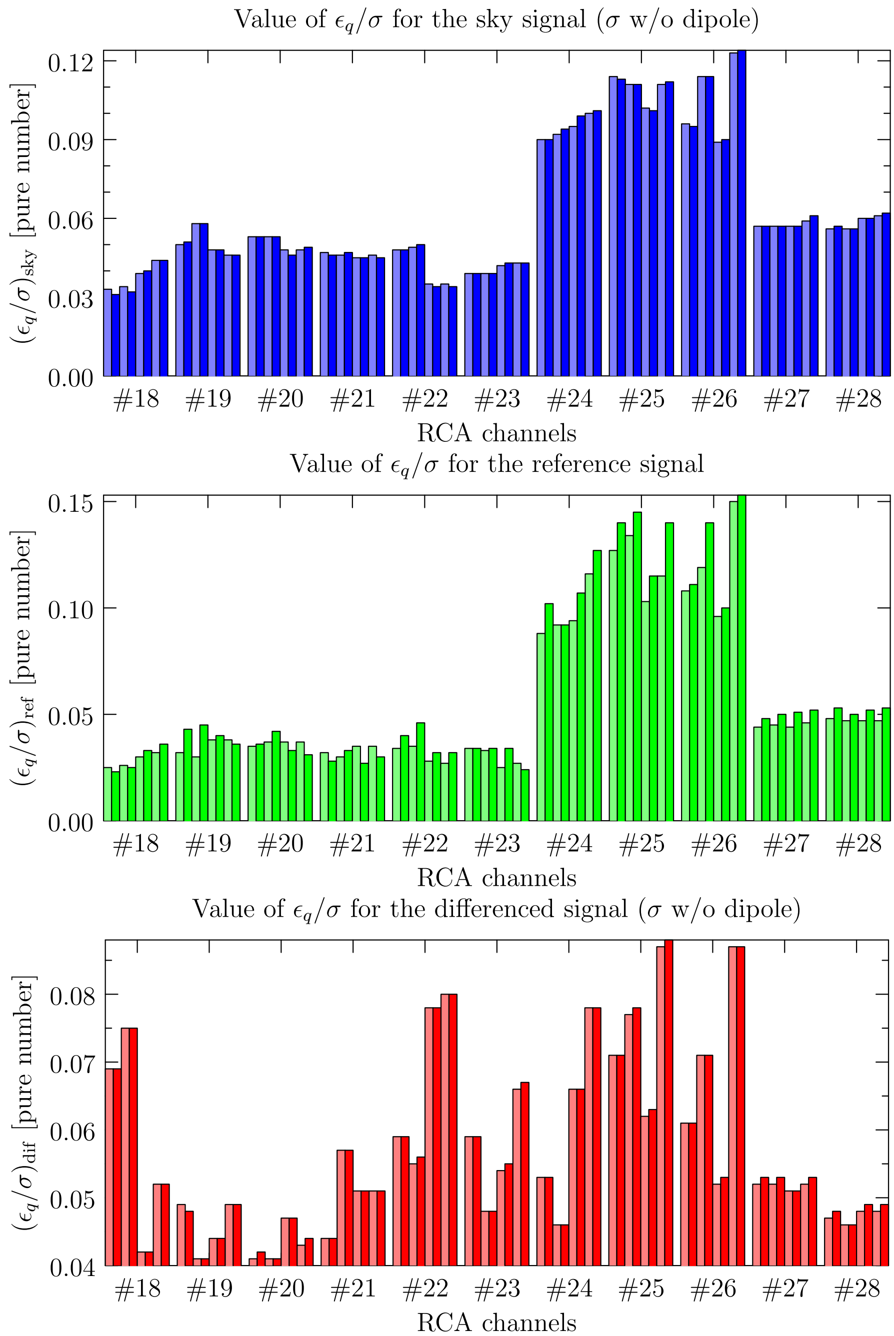

Figure 3: Ratio between the quantization error and the intrinsic RMS of the sky, reference and differenced signals for the second REBA calibration (light bars) and verification (dark bars) tests.

	First calibration (OD64)				Second calibration (OD75)			
Ch.	r_1	r_2	Δ	s_q	r_1	r_2	Δ	s_q
1800	-0.3768	0.9500	-6781.780	0.616	1.0000	0.5000	-2027.88	0.70
1801	0.9163	1.0703	377.190	2.663	1.0000	0.5000	-2729.95	1.05
1810	1.0417	0.5000	-2148.040	1.950	0.9688	0.3750	-235.66	0.77
1811	0.8797	1.0805	149.472	3.438	1.0833	0.5000	-1913.74	1.07
1900	1.0833	0.5000	-2112.950	0.999	1.0833	0.5000	-2157.77	1.02
1901	1.1250	0.5000	-1211.480	0.982	1.0833	0.5000	-72.47	1.04
1910	1.1667	0.5000	-791.920	1.349	1.1250	0.5000	-85.87	1.66
1911	1.1667	0.5000	-1427.150	1.081	1.0833	0.5000	-1073.16	1.37
2000	1.2083	0.5000	-701.960	0.809	1.1250	0.5000	-95.77	0.98
2001	1.2083	0.5000	-891.930	0.786	1.1667	0.5000	-138.38	0.95
2010	1.0833	0.5000	-1386.300	1.562	1.1250	0.5000	-1788.48	0.95
2011	1.0833	0.5000	-1333.050	1.655	1.1667	0.5000	-273.73	1.01
2100	1.0000	0.5000	-1996.150	1.246	1.0417	0.5000	-223.40	1.76
2101	1.0417	0.5000	-1712.700	1.239	1.0417	0.5000	-2632.33	1.79
2110	0.8600	1.0400	27.800	2.730	1.0833	0.5000	-1104.30	1.48
2111	1.0417	0.5000	-1670.860	1.976	1.0833	0.5000	-1372.34	1.38
2200	1.1250	0.5000	-1421.060	1.122	1.0417	0.5000	-2890.26	2.62
2201	1.1250	0.5000	-1453.000	1.186	1.0833	0.5000	-2634.94	2.38
2210	1.0417	0.5000	-3015.560	0.924	1.0417	0.5000	-3069.98	1.84
2211	1.0417	0.5000	-2882.510	0.798	1.0417	0.5000	-3199.96	1.48
2300	1.0417	0.5000	-1654.220	1.071	1.0417	0.5000	-1204.43	1.37
2301	1.1250	0.5000	-1970.910	0.938	1.0417	0.5000	-388.72	1.20
2310	1.0417	0.5000	-2273.180	1.021	1.0000	0.5000	-884.04	1.31
2311	1.0417	0.5000	-1462.610	0.912	1.0000	0.5000	-3042.10	2.29
2400	0.8700	1.0600	-79.670	6.120	0.9583	0.5000	-3181.09	4.54
2401	0.8600	1.0800	-41.890	6.860	1.0417	0.5000	-2727.14	3.56
2410	0.8700	1.0600	-45.250	6.280	0.8750	0.5000	-3515.08	5.84
2411	0.8500	1.0500	-114.800	6.710	0.8333	0.5000	-4039.87	6.10
2500	1.0833	0.5000	-1709.350	3.931	0.8333	0.5000	-3734.20	6.32
2501	1.1250	0.5000	-1393.070	3.849	0.8333	0.5000	-3936.60	6.40
2510	0.8100	1.0500	-257.150	5.250	0.8750	0.5000	-3472.95	5.40
2511	0.7100	1.1100	-463.610	4.280	0.7917	0.5000	-3964.33	7.68
2600	0.7700	1.0400	-369.290	5.100	0.8750	0.5000	-3302.25	5.24
2601	0.7800	1.0400	-243.880	4.150	0.8333	0.5000	-3558.53	6.66
2610	0.8300	1.0500	-110.150	5.560	0.9583	0.5000	-3102.14	4.25
2611	0.9200	1.1200	565.140	7.600	0.7917	0.5000	-3985.84	7.68
2700	0.6200	0.9000	15.130	1.630	1.2917	0.3750	1931.44	1.28
2701	1.5000	0.5000	3639.000	1.120	1.2917	0.3750	2270.51	1.20
2710	0.6200	0.8900	8.820	1.640	1.2500	0.3750	1876.51	1.34
2711	0.5500	0.9700	-301.700	1.760	1.3333	0.3750	1645.06	1.44
2800	1.5000	0.5000	535.500	1.493	1.3750	0.3750	-470.12	1.49
2801	1.5000	0.5000	937.400	1.201	1.3750	0.3750	124.87	1.22
2810	0.6900	0.9800	-238.650	2.250	1.3333	0.3750	495.68	1.73
2811	0.6600	0.9400	-208.290	2.490	1.3333	0.3750	386.56	1.92

Table 5: The best parameters found in the analysis done on the data from the two calibration tests. These parameters have been uploaded onboard on July, 20th 2009 and on July, 29th 2009. The latter is the table currently used for the all-sky survey.

FEM	V_g^1	V_g^2	V_d	I_1	I_2	Ph/sw pos.	4 kHz	Offs.	Gain	I_d [mA]
18M1	195	189	126	255	255	1	0	120	1	13.7
18M2	198	201	125	255	255	0	1	140	1	15.0
18S1	155	215	138	255	255	0	1	24	0	16.5
18S2	216	182	114	255	255	1	0	24	1	19.0
19M1	205	221	124	255	255	1	0	160	9	20.2
19M2	196	216	126	255	255	0	1	148	9	19.6
19S1	202	226	120	255	255	0	1	132	9	18.2
19S2	207	222	125	255	255	1	0	144	9	18.0
20M1	191	244	121	255	255	1	0	120	2	21.3
20M2	209	231	127	255	255	0	1	120	2	21.3
20S1	179	230	132	255	255	0	1	89	9	17.6
20S2	169	215	127	255	255	1	0	87	9	16.9
21M1	192	231	147	255	255	1	0	154	2	21.5
21M2	191	224	136	255	255	0	1	154	2	23.6
21S1	170	221	136	255	255	0	1	160	9	19.2
21S2	205	243	132	255	255	1	0	165	9	22.1
22M1	208	218	130	255	255	1	0	163	9	18.7
22M2	188	188	135	255	255	0	1	130	9	18.6
22S1	210	221	128	255	255	0	1	130	9	21.2
22S2	193	231	130	255	255	1	0	130	9	19.0
23M1	211	206	120	255	255	1	1	40	8	17.3
23M2	190	228	119	255	255	1	0	120	9	17.6
23S1	180	222	123	255	255	1	0	100	9	21.9
23S2	198	213	127	255	255	1	1	146	9	17.8
24M1	219	204	183	98	215	0	1	255	4	7.3
24M2	227	204	183	77	185	0	0	255	11	7.1
24S1	218	207	157	84	235	0	1	255	4	8.3
24S2	225	208	152	86	205	0	0	255	4	7.7
25M1	231	203	177	154	245	0	0	255	10	6.3
25M2	218	200	178	79	255	0	1	255	10	6.3
25S1	231	196	167	79	205	0	0	255	10	6.1
25S2	223	199	166	119	225	0	1	255	10	6.0
26M1	247	203	169	108	255	0	1	255	4	8.1
26M2	226	200	170	153	165	0	0	255	4	8.5
26S1	227	194	172	135	235	0	1	255	10	6.5
26S2	240	197	169	93	225	0	0	250	4	6.2
27M1	242	97	156	148	220	0	0	143	9	7.9
27M2	255	96	157	145	205	0	1	132	9	7.5
27S1	235	86	157	127	184	0	0	138	9	8.2
27S2	248	113	156	148	195	0	1	160	9	8.0
28M1	243	101	150	130	160	1	0	160	9	9.0
28M2	240	112	163	127	228	0	1	134	9	9.8
28S1	235	81	157	127	222	1	0	160	9	8.8
28S2	249	90	158	103	165	0	1	160	9	9.4

Table 6: Biases used during the first calibration (July, 16th 2009). All the values but the drain current I_d are reported in DEC (raw) units. The value of I_d is the average calculated on the first five minutes of the test (15:00:00z - 15:05:00z).

FEM	V_g^1	V_g^2	V_d	I_1	I_2	Ph/sw pos.	4 kHz	Offs.	Gain	I_d [mA]
18M1	195	189	126	255	255	1	0	65	9	13.1
18M2	198	201	125	255	255	0	1	135	9	14.4
18S1	155	215	138	255	255	0	1	53	1	15.9
18S2	216	182	114	255	255	1	0	63	2	18.5
19M1	213	206	124	255	255	1	0	147	9	18.2
19M2	211	208	126	255	255	0	1	146	9	19.9
19S1	215	209	120	255	255	0	1	94	9	17.9
19S2	204	216	125	255	255	1	0	146	9	17.0
20M1	209	219	121	255	255	1	0	132	9	20.7
20M2	215	221	127	255	255	0	1	93	9	20.7
20S1	199	221	132	255	255	0	1	82	9	18.8
20S2	188	201	127	255	255	1	0	80	9	18.7
21M1	198	207	141	255	255	1	0	155	9	18.5
21M2	196	197	136	255	255	0	1	156	9	19.5
21S1	170	221	136	255	255	0	1	204	9	19.1
21S2	205	243	132	255	255	1	0	149	9	22.0
22M1	203	194	125	255	255	1	0	223	9	14.1
22M2	178	176	130	255	255	0	1	206	9	14.8
22S1	204	189	128	255	255	0	1	224	9	16.4
22S2	206	204	130	255	255	1	0	229	9	15.1
23M1	207	192	120	255	255	1	1	130	9	14.7
23M2	210	195	119	255	255	0	0	224	9	14.2
23S1	181	211	118	255	255	0	0	122	9	20.6
23S2	190	208	122	255	255	1	1	144	9	14.8
24M1	225	225	191	205	205	0	1	255	11	16.5
24M2	225	225	185	205	206	0	0	255	11	15.0
24S1	225	225	158	205	205	0	1	255	10	15.5
24S2	225	225	159	205	205	0	0	255	10	16.4
25M1	225	225	185	205	205	0	0	255	3	14.3
25M2	225	225	187	205	205	0	1	255	3	14.8
25S1	225	225	169	205	205	0	0	255	3	14.8
25S2	225	225	167	205	205	0	1	255	3	14.6
26M1	225	225	176	205	205	0	1	255	3	12.8
26M2	225	225	178	205	205	0	0	255	10	14.7
26S1	225	225	178	205	205	0	1	255	3	13.7
26S2	225	225	176	205	205	0	0	255	10	13.4
27M1	240	108	156	148	220	0	0	112	9	8.1
27M2	244	90	157	145	205	0	1	100	9	7.2
27S1	237	102	157	127	184	0	0	106	9	8.5
27S2	246	114	156	148	195	0	1	132	9	8.0
28M1	243	101	157	130	160	1	0	139	9	9.6
28M2	240	112	156	127	228	0	1	98	9	9.2
28S1	240	84	157	127	222	1	0	137	9	9.1
28S2	245	121	158	103	165	0	1	152	9	10.5

Table 7: Biases used during the second calibration (July, 27th 2009). All the values but the drain current I_d are reported in DEC (raw) units. The value of I_d is the average calculated on the first five minutes of the test (14:00:12z - 14:05:12z).

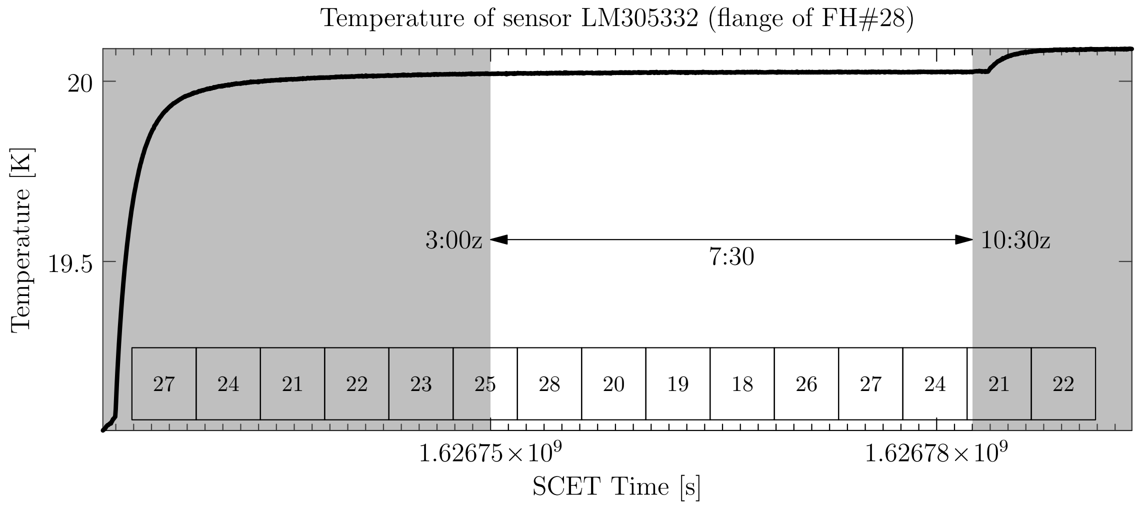

Figure 4: Temperature of one of the focal plane sensors during OD67. The segments of data in AVR1 (uncompressed) mode are shown in the plot as boxes (each box lasts 1 hour). The warm-up of the LFI prevented us from having AVR1 data in stable conditions for many radiometers. We therefore used only data from 3:00z till 10:30z.

4 REBA Verification Test Execution

4.1 Procedure/Test Sequence

The verification of the calibration of the REBA compressor is conceptually simple: the LFI is kept in its nominal state with the 44 detectors acquiring data in COM5 (compressed) mode and with one detector at time acquiring data in AVR1 (uncompressed) mode for 15 minutes as well (see [RD1] and [AD1]). The time required to have enough data for a verification would be 22 hours (i.e. having two AVR1 chunks of 15 minutes each per each detector). However, both during the first verification and the second one we were forced to use less data:

1. A problem in the LFI REBA turned LFI off on July, 19th 2009. After its restart (21:00z) and warm-up, the thermal environment reached stability at 3:00z of the following day. Therefore, only a subset of the 44 channels were acquired in AVR1 mode in stable conditions during the first verification (OD67). See figure 4.

2. Due to some constraints with the schedule, during the second verification test (OD77) we decided to acquire data for only 11 hours. Although the required amount of AVR1 data was not collected (i.e. we had only 15' of AVR1 data per channel instead of 30'), it has nevertheless been enough to ensure that the calibration of the REBA was performed correctly.

In the next paragraphs we present the detailed results of the analysis done on the two chunks of data.

4.2 Analysis Codes

We used the Reverie module from the LIFE software suite to determine the quantization and the compression ratio of the compressed data during OD67 and OD77. The following lines of code

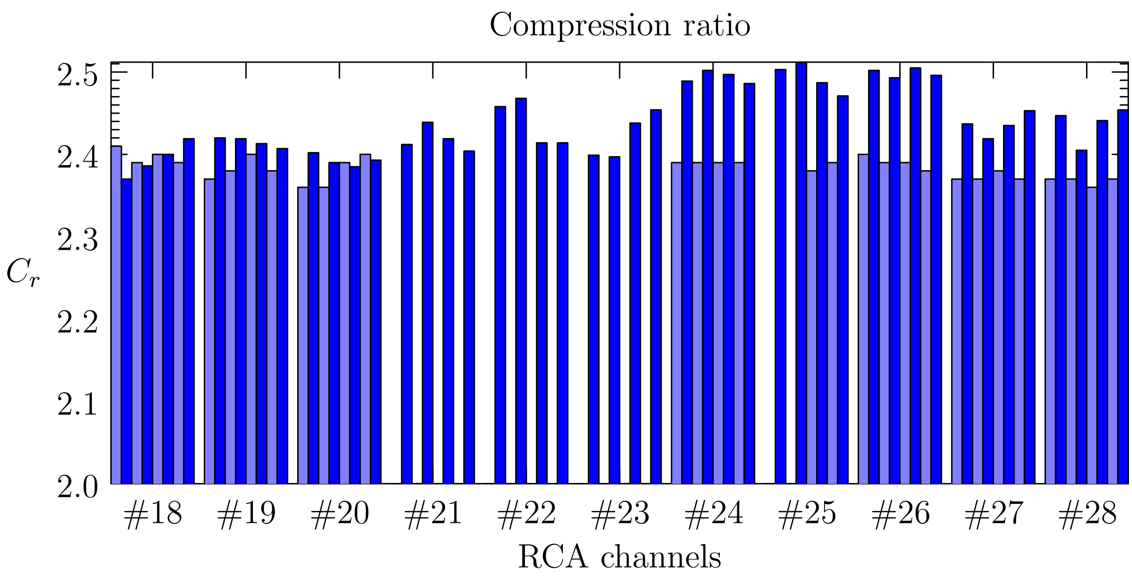

Figure 5: Comparison of the compression ratios between the two *verification* tests. Unlike figure 1, here we show only measured values taken for two different configurations of the REBA. Light bars show the results of the first test (OD67) and dark bars the results of the second (OD77). The good result obtained for the 44 GHz channel has been achieved at the expense of the quantization error, see figure 6.

run Reverie on the data and generates a LaTeX report containing the same results displayed in Table 8:

```
od63 = reverie ('pegaso', [25, 28, 20, 19, 18, 26, 27, 24],
                start_time = 1626742800d, end_time = 1626769800d,
                /report, /normalize_rms)
od77 = reverie ('pegaso', -1,
                start_time = 1627595644d, end_time = 1627635123d,
                /report, /normalize_rms)
```

4.3 Discussion of the Results

The results of the verification are listed in Table 8 for both OD67 and OD77. There are many missing entries for OD67 because of the thermal drift experienced at the beginning of the test (see section 4.1).

The telemetry rate used to transmit COM5 compressed data (i.e. excluding the calibration channel and housekeeping information) is reported in the following table:

		Calibration	Verification
First run	(OD67)	37 342	> 23 117
Second run	(OD77)	38 057	37 114

The quantization measured during the verification tests compares quite well with the values estimated during the calibration, as plots 1, 2 and 3 show. During OD77 we measured in many cases higher values in the value of the compression ratio, c_r.

The quantization level in the differenced signal was better during the first calibration, the average of $(\epsilon_q/\sigma)_{\mathrm{dif}}$ being 4.7% in OD67 and 5.7% in OD77. Note also that the 44 GHz channels have a higher quantization rate in the second calibration (which however helps in improving the compression ratio c_r): refer to figures 5 and 6. This is due to the less refined strategy used to calibrate the data: as explained in section 3.2.1, we applied a number of different calibration strategies during the first calibration, while the second one was performed automatically[5].

[5] One must however note that during the first calibration we produced wrong values for channel #1800 (not achieving the requirement $\epsilon_q/\sigma < 1$ in the quantization of the differenced signal). This was due to a human mistake that would have been impossible if we used an automatic procedure like in the second case.

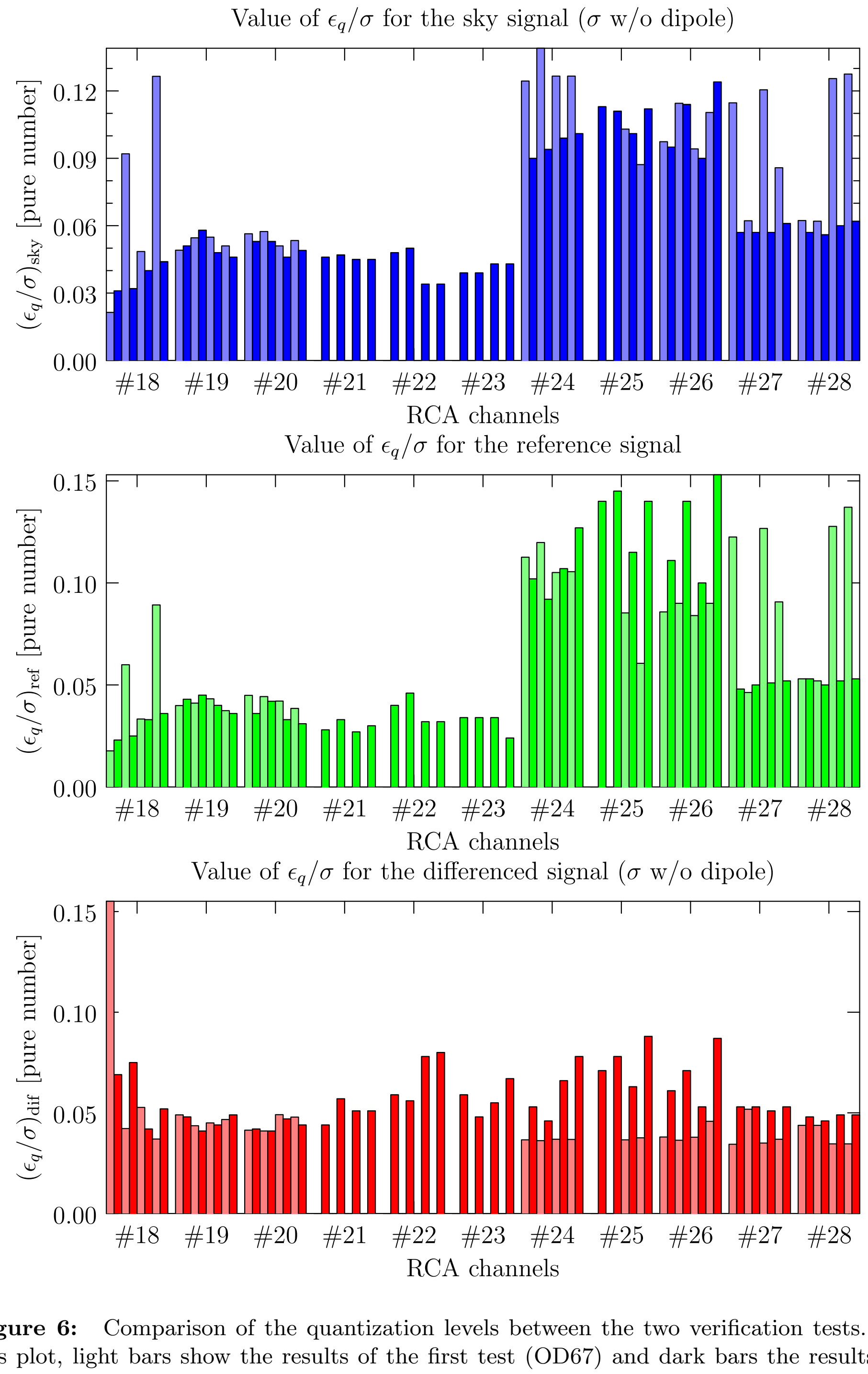

Figure 6: Comparison of the quantization levels between the two verification tests. In this plot, light bars show the results of the first test (OD67) and dark bars the results of the second (OD77).

	First verification (OD67)					Second verification (OD77)				
Ch.	c_r	$\left(\frac{\epsilon_q}{\sigma}\right)_{\text{sky}}$	$\left(\frac{\epsilon_q}{\sigma}\right)_{\text{ref}}$	$\left(\frac{\epsilon_q}{\sigma}\right)_{\text{dif}}$	Rate	c_r	$\left(\frac{\epsilon_q}{\sigma}\right)_{\text{sky}}$	$\left(\frac{\epsilon_q}{\sigma}\right)_{\text{ref}}$	$\left(\frac{\epsilon_q}{\sigma}\right)_{\text{dif}}$	Rate
1800	2.41	0.021	0.018	0.155	1102.2	2.37	0.031	0.023	0.069	1107.0
1801	2.39	0.092	0.060	0.042	1107.0	2.39	0.032	0.025	0.075	1100.2
1810	2.40	0.049	0.033	0.053	1105.8	2.40	0.040	0.033	0.042	1093.8
1811	2.39	0.127	0.089	0.037	1105.8	2.42	0.044	0.036	0.052	1085.3
1900	2.37	0.049	0.040	0.049	1115.0	2.42	0.051	0.043	0.048	1084.5
1901	2.38	0.055	0.041	0.044	1111.2	2.42	0.058	0.045	0.041	1084.9
1910	2.40	0.055	0.043	0.045	1105.1	2.41	0.048	0.040	0.044	1087.7
1911	2.38	0.051	0.037	0.047	1110.3	2.41	0.046	0.036	0.049	1090.0
2000	2.36	0.056	0.045	0.041	1118.5	2.40	0.053	0.036	0.042	1092.5
2001	2.36	0.057	0.044	0.041	1119.9	2.39	0.053	0.042	0.041	1098.0
2010	2.39	0.051	0.042	0.049	1106.6	2.38	0.046	0.033	0.047	1100.3
2011	2.40	0.053	0.038	0.048	1103.4	2.39	0.049	0.031	0.044	1096.7
2100						2.41	0.046	0.028	0.044	1087.9
2101						2.44	0.047	0.033	0.057	1076.1
2110						2.42	0.045	0.027	0.051	1084.8
2111						2.40	0.045	0.030	0.051	1091.6
2200						2.46	0.048	0.040	0.059	1067.5
2201						2.47	0.050	0.046	0.056	1063.4
2210						2.41	0.034	0.032	0.078	1086.7
2211						2.41	0.034	0.032	0.080	1087.5
2300						2.40	0.039	0.034	0.059	1094.1
2301						2.40	0.039	0.034	0.048	1094.8
2310						2.44	0.043	0.034	0.055	1076.1
2311						2.45	0.043	0.024	0.067	1069.2
2400	2.39	0.124	0.113	0.037	654.7	2.49	0.090	0.102	0.053	623.0
2401	2.39	0.139	0.120	0.036	655.0	2.50	0.094	0.092	0.046	619.9
2410	2.39	0.127	0.105	0.037	234.7	2.50	0.099	0.107	0.066	621.1
2411	2.39	0.127	0.105	0.037	654.6	2.49	0.101	0.127	0.078	623.7
2500						2.50	0.113	0.140	0.071	619.6
2501						2.51	0.111	0.145	0.078	617.5
2510	2.38	0.103	0.085	0.037	659.1	2.49	0.101	0.115	0.063	623.3
2511	2.39	0.087	0.061	0.038	655.1	2.47	0.112	0.140	0.088	627.2
2600	2.40	0.097	0.086	0.038	653.6	2.50	0.095	0.111	0.061	619.8
2601	2.39	0.115	0.090	0.036	654.4	2.49	0.114	0.140	0.071	622.0
2610	2.39	0.094	0.084	0.038	653.5	2.50	0.090	0.100	0.053	619.2
2611	2.38	0.110	0.090	0.046	656.9	2.50	0.124	0.153	0.087	621.4
2700	2.37	0.115	0.122	0.034	458.6	2.44	0.057	0.048	0.053	444.1
2701	2.37	0.062	0.046	0.052	459.5	2.42	0.057	0.050	0.053	447.9
2710	2.38	0.120	0.127	0.035	458.5	2.44	0.057	0.051	0.051	444.7
2711	2.37	0.086	0.091	0.037	459.2	2.45	0.061	0.052	0.053	441.7
2800	2.37	0.062	0.053	0.044	458.9	2.45	0.057	0.053	0.048	442.5
2801	2.37	0.062	0.052	0.044	459.7	2.40	0.056	0.050	0.046	450.1
2810	2.36	0.126	0.128	0.035	461.1	2.44	0.060	0.052	0.049	443.8
2811	2.37	0.128	0.137	0.035	459.6	2.45	0.062	0.053	0.049	441.3

Table 8: Results of the two REBA verification tests.