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Contents

Abstract

In this report we show the results of the DAE calibration activity performed during the CPV test phase of the Planck/LFI instrument. The activity has the purpose of finding the best gain and offset values for the 44 ACA implemented in the LFI, and to characterize the so-called "offset problem", i.e. a spurious offset that the DAE applies to scientific data under some conditions.

During the CPV phase the DAE calibration has been repeated twice, because after the first calibration a new configuration for the LFI ACA biases has been loaded and the absolute voltage levels fed to the DAE have changed consequently. This document shows the results for both calibrations.

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1 Applicable and Reference Documents

Reference Documents

[] Data Analysis of the DAE offset and DAE gain tuning and verification. Technical Report LFI-PST-RP-045, 2008.

[] Aniello Mennella. Data analysis and scientific performances of the LFI FM instrument. Technical Report PL-LFI-PST-AN-006, UniMI, 2006.

Applicable Documents

[] Anna Gregorio. Testing plan of the LFI instrument during the Planck Commissioning and CPV phase. Technical Report PL-LFI-PST-PL-043, OATS, 2009.

[] Maurizio Tomasi. Analysis of the DAE offset problem. Technical Report PL-LFI-PST-TN-085, UniMi, May 2008.

2 Introduction

2.1 Purpose and Scope

The offset removal and gain stages in the LFI DAE are two analogue circuits whose main objective is to optimise the DC voltage output from each BEM channel to the DAE 14 bit ADC input. This is done by first removing a fixed offset and then multiplying the signal by a gain factor ranging from 1 to 48 [**? ?**].

The DAE tuning test has two objectives:

1. to characterize the correct offset removal for all offset and gain stages. This is done because during ILT it was discovered that for some of the offset stages the offset was removed differently for sky and reference samples. This called for an activity to be repeated in flight in order to characterised the offset values for which this effect is seen in order to avoid using them;

2. to find the optimal gain and offset parameters for the given bias configuration in order to properly resolve the radiometer noise without saturating the ADC input.

These two objectives are accomplished by a test in which all the offset and gain stages are exercised and the corresponding voltage output is recorded. The following sections explain these points with greater detail.

2.2 Details of the DAE Digitization

The voltage V coming from the BEM amplifiers undergoes the following transformation before entering each of the 44 ADC converters implemented in the DAE:

$$d = (V - V_{\mathrm{ofs}}) \times g + d_{\mathrm{zero}}, \tag{1}$$

DEC value	Physical gain
0	1
1	2
8	3
2	4
9	6
3	8
10	12
4	16
11	24
15	48

Table 1: Possible values for g, the DAE gain, and the relation between the DEC value (used to program the DAE) and the physical gain applied to the voltages.

where V_{ofs} and g are two user-defined parameters (one pair for each LFI channel) and d_{zero} is a corrective offset added by the DAE which depends on g. The number d is a 14-bit integer which is sent to the REBA to be binned and compressed. We call V_{ofs} the *DAE offset* and g the *DAE gain*. Once the signal has been recovered on ground, the inverse of eq. (1) is applied:

$$V = \frac{d - d_{\text{zero}}}{g} + V_{\text{ofs}}, \tag{2}$$

and the original voltage (plus some noise due to digitization) is recovered.

The purpose of the DAE calibration is to find the best values for V_{ofs} and g for each of the 44 ADC converters. This is accomplished by following these criteria:

1. The voltage before the amplification stage ($V - V_{\text{ofs}}$) must lie in the interval 0.0 V - 2.5 V, as this is the operating range of the ADC amplifier;

2. The value of g should be as large as possible, in order to reduce the quantization noise on the signal;

3. The result value of eq. (1) should not exceed the 14-bit range in order to prevent saturation (i.e. d should be in the interval $[0, 2^{14} - 1]$).

The values for g and V_{ofs} (and consequently d_{zero}) are set through an integer number – the *DEC value* — which is mapped by the DAE hardware to the true value. The following rules apply:

1. There are 255 steps of offset that can be used to program V_{ofs}, from 0.0 V to 2.5 V. The steps vary with a roughly linear law.

2. There are 10 gain steps available for g; the mapping between their DEC value and the real gain is shown in table 1.

2.3 The no-fly zone

During the RAA FM tests it was discovered that there are a few configurations of the DAE offset where the real offset applied to the data depends on the level of the input voltage [**?**]. Since the input consists of alternating samples measuring the sky (~ 2.7 K) and the reference loads (~ 4.5 K), this implies that a different offset is applied to sky and reference samples, which in turn produce a constant offset in the differenced data.

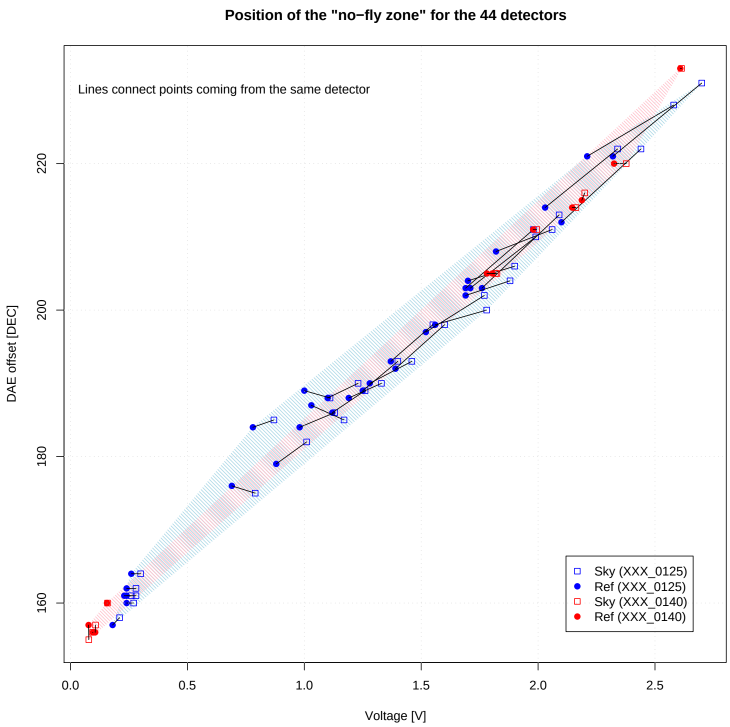

Figure 1: Position of the so-called *no-fly zone* for two tests done during the LFI RAA FM tests (image taken from [**?**]). The points that fall within the shaded region show a spurious offset in the ADC output which depends on the absolute input voltage (X axis) and the DAE offset value applied for that channel (Y value, in DEC units).

This effect is easily seen by exercising each state of V_{ofs} and then de-calibrating the DEC values produced by the DAE using eq. (2). As the purpose of the equation is to retrieve the original voltage that entered the DAE (which did not change by definition while changing V_{ofs}), we expect that for an ideal instrument the sequence of values for V should be roughly at the same value. What it is seen on the real instrument is that for a very narrow region (a few steps in V_{ofs}) there are sudden "jumps" in the value of V [**?**].

Although the cause of such effect has not been discovered yet, the LFI calibration team has discovered that the effect is remarkably stable and that the range of affected V_{ofs} values is quite narrow, see fig. 1. Therefore we have produced a map in the voltage-vs-offset plane of the so-called *no-fly zone* during the RAA FM tests and have kept it as a reference for every subsequent calibration of the DAE.

2.4 Test Configuration

The test configuration is the following:

- SCOS 2K EGSE 3.1 Release 1.2
- RTSILib version 1.0
- RTSI Client version 1.2

- LEVEL1 (TMH/TQL) version 5.1
- LIFE Machine version OM 3.00
- IDIS 2.7.3.4

The LFI personnel involved during the test is listed in the following table:

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Industry support	

2.5 Pass-fail criteria, verification matrix

Test name: DAE offset/gain tuning

Test objectives: The objective of this test is to exercise the offset circuitry in order to verify the DAE offset and gain values at the end of the amplifier chain. During the FM test was discovered that the offset value applied by circuitry has some dependence from the input signal, so a sort of calibration/adjustment activity is foreseen to obtain data that could be checked for performances of the instrument. (Refer to FM Test Report or to NC 4122).

Verification matrix					
Check	**Passed?**			**Recovered?**	
	Yes	**No**	**Notes**	**Yes**	**No**
No unexpected event packets	Yes				
TC Procedure	Yes				
No unexpected features	Yes				

3 Description of the Tests

The test is divided into two parts [?]:

1. The first one (*calibration*) acquires data while exercising the 44 ADC converters in each possible configuration; such data are used to determine the best values for V_{ofs} and g for each converter.

   The data acquisition for the calibration phase requires the REBA to acquire data in AVR1 (uncompressed) mode while exercising all the gain and offset states of the DAE ($10 \times 255 =$

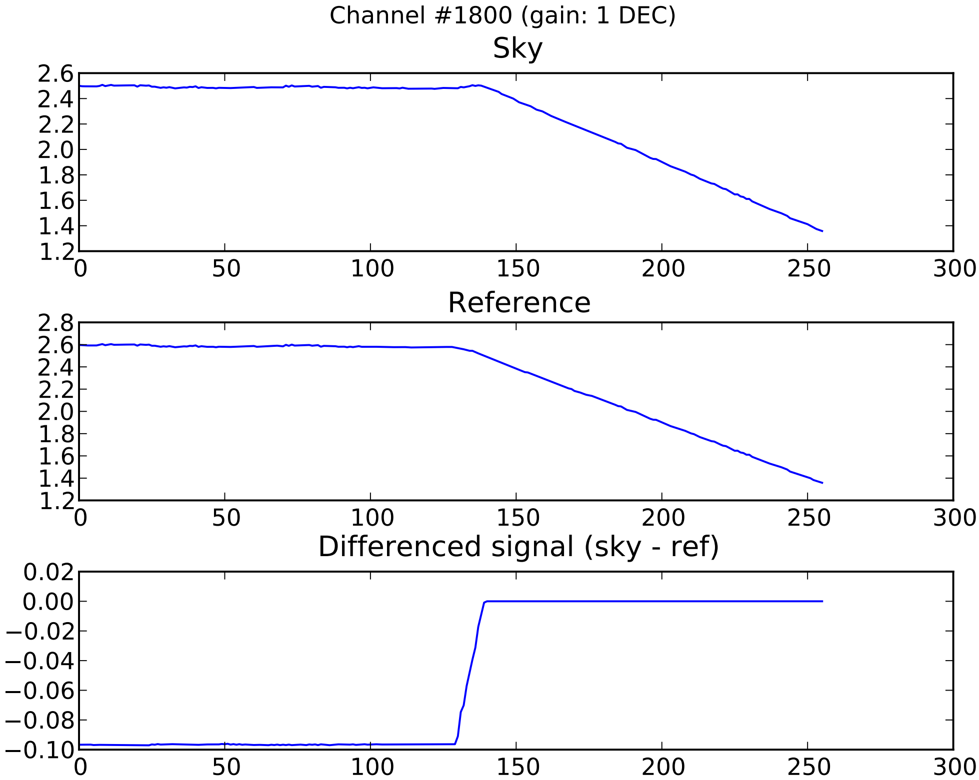

Figure 2: Example of the data acquired during the first calibration (channel #1800, gain state is 1 DEC). The average output voltage (y) is plotted against the raw DAE offset value (x). Note that for offsets smaller than ∼130 DEC the output voltage after the digital-to-voltage calibration does not change (as the input voltage does not as well): this is the normal behavior. However, for offsets greater than 130 DEC the ADC saturates and therefore eq. (2) is adding an offset that is no longer the same used in eq. (1). This is most easily seen in the differenced data, which exhibit a sudden jump.

2 550 states) and acquiring each of them for 30 seconds. The order used to change the states is to start from the lowest gain state (0 DEC) and exercise all the 255 gain states ($255 \to 0$), then increase the gain by one unit and repeat. See fig. 2 for an example.

As the 44 ADCs are independent and do not exhibit cross-talk effects, it is possible to change their state in parallel. The whole acquisition requires something more than 21 hours to complete ($2\,550 \times 30\,\mathrm{s}$).

2. The second part (*verification*) is performed after having uploaded the best configuration in the DAE, and it simply requires to acquire data for some time in order to verify that the output of each ADC is at the expected level and that there are no saturations. This is an easy task that can be accomplished simply by looking at the output voltages in the TQL screen.

	g	t_0	t_1
First calibration (OD61)	0	1 626 183 004	1 626 191 199
	1	1 626 191 199	1 626 199 394
	8	1 626 199 394	1 626 207 588
	2	1 626 207 588	1 626 215 783
	9	1 626 215 783	1 626 223 980
	3	1 626 223 980	1 626 232 174
	10	1 626 232 174	1 626 240 369
	4	1 626 240 369	1 626 248 564
	11	1 626 248 564	1 626 256 759
	15	1 626 256 759	1 626 264 954
Second calibration (OD74)	0	1 627 380 599	1 627 383 600

Table 2: Time ranges for the two calibration tests. The first one (July, 7-8th 2009) has exercised all the 10 DAE gain states in order to check that the no-fly zone (see section 2.3) is independent from the gain. Once this has been assessed, the second calibration (July, 27th 2009) simply applied the lowest gain state.

Since the results of the DAE calibration depend on the absolute voltage entering each diode in the DAE, this means that each time the configuration of the FEMs changes the calibration needs to be repeated. This has happened once during the CPV phase, when a number of FEM amplifiers were tuned again after having shown noise properties worse than expected [REF?]. See tables 5 and 6 for the FEM biases used during the first and the second test. This document presents the results of both DAE calibrations: of course, the calibration used in the FLS and in the nominal survey is the latter.

3.1 Data available for the Calibration

Table 2 lists the data that were available for the two calibrations mentioned in the previous paragraph. The first calibration tested each pair of (g, V_{ofs}) values and its main purpose was to check the stability of the “no-fly zone” when the gain varies (a test that was not possible to perform during the RAA FM tests due to tight schedule constraints). As the first test confirmed the stability of the effect, the second test only applied one gain value, therefore reducing the acqusition time from one day to one hour.

3.2 Data Available for the Verification

A first rough verification has been performed immediately after having uploaded the calibrated DAE gains and offsets. The verification essentially checks that the values output by the ADC are the same (within some threshold) as the one expected during the calibration, that is, they must fall within the $[0, 2^{14} - 1]$ interval and stay away from the borders. This quick verification has been made after both calibrations by simply check the output values on the TQL screen.

The best place where to perform an accurate verification of the DAE calibration is of course the data from the First Light Survey (FLS), that is, the data acquired between OD91 and OD105. This report only considers this kind of verification.

3.3 Calibration Methods and Criteria

Section 2.2 has pointed out the purpose and the constraints of the DAE tuning process. These are however not enough to uniquely fix the values of the DAE gain g and offset $V_{\rm ofs}$. During the CPV tests we have tuned each ADC following this approach:

1. For each detector we have calculated the $V_{\rm ofs}$ that makes $V - V_{\rm ofs} \approx 0.5\,\mathrm{V}$. This ensures that each ADC receives roughly the same input voltage. For those detectors where this was not possible (e.g. 44 GHz have an output level usually lower than 0.5 V), we assumed $V_{\rm ofs} = 0\,\mathrm{V}$.

2. Using the value of $V - V_{\rm ofs}$ we have calculated the value of g so that eq. (1) produces the largest possible value within ∼75÷80% of the dynamic range.

3. Once the best values for the gain and the offset are found, we have checked the offsets manually in order to guarantee that they do not fall within the no-fly region (see sec. 2.3).

4 Data Analysis

4.1 Calibration

In both the calibration tests we followed the rules listed in sect. 3.3 to obtain a set of DAE gains and offset. This has been done by means of a number of scripts in IDL and Python that retrieve scientific data from Pegaso and split the datastream of each channel into chunks based on the DAE configuration[1]. Within each chunk, the average voltage level has been calculated and used to determine the best configuration of parameters.

The results of the two calibrations are reported in table 3 and 4.

4.2 Determination of the No-Fly Zone

During the first calibration we were able to find the points where the applied DAE offset changes with the input voltage. This analysis has been done for the first two gain states, as higher gains make the problem invisible[2].

The results of the analysis are shown in fig. 3. The analysis of the CPV data has produced less points than the one made on the RAA FM data. This happened because of a number of factors, the most relevant being the fact that in the RAA tests we kept each DAE offset state for one minute, while in flight the time was reduced to one half: this has produced noisier data, which in some cases has forbidden us to clearly mark the point where the jump occurred. However, for those channels where the jump was recognizable we found a remarkable agreement with the behavior observed during the RAA tests. This is a good news, since it implies that the effect has shown no degradation since the last time it has been measured (Summer 2006).

4.3 Verification

The verification of the DAE calibration has been performed quickly after each table of gains and offsets has been uploaded onboard. However, a more careful verification has been made after the completion of the First Light Survey, when the LFI was operated in nominal mode for 15 days. To verify the calibration of the DAE we have produced the plot shown in fig. 4, where for each

[1] This means 255×10 chunks for the first calibration – which exercised all the 10 gain states – and 255 for the second one, which only used $g = 0\,\mathrm{DEC}$.

[2] This happens because with high gain values it is more likely to set a value of $V_{\rm ofs}$ which makes the ADCs saturate. Therefore, the greater the gain the more garbage is produced while spanning the range of offsets.

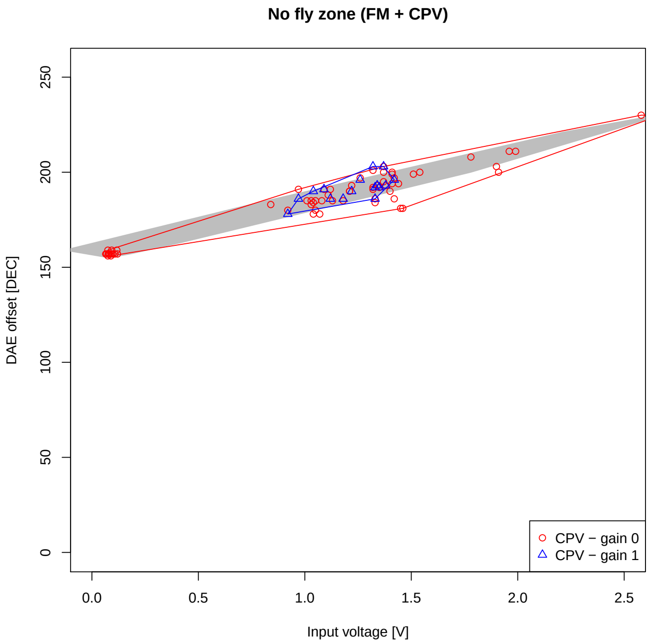

Figure 3: Plot of the no-fly zone. Grey area: RAA FM test data (the same region shown in fig. 1). Red and the blue areas: CPV data from the first calibration with gain 0 (red) and 1 (blue). The red and blue regions are narrower than the grey one because during the RAA FM tests the effect was clearer (no dipole, longer integration per each offset step...). The important result here is that the three regions overlap, which means that the effect has not drifted in the last three years.

channel the minimum and maximum value output by the DAE have been plotted on an horizontal line. The only channel that shows a saturation is #2411 (the maximum value reaches 16 383): this was due to a misconfiguration during the first day of the FLS (OD91) and has been quickly fixed in the same day. Therefore, at the end of the FLS all the channels have shown to behave as expected.

5 Conclusions

In this report we discussed the procedures and the results of the DAE calibration activity during the CPV phase. The calibration has the purpose of finding the best values for the offset and the gain applied by the DAE to the input voltage before the digitization. Finding the best parameters means to find a couple (g, V_{ofs}) of values for each of the 44 ADC that makes the following statements true: (1) there are no saturations in the signal leaving the DAE, and (2) the output optimally uses the allowed digital range $[0, 2^{14} - 1]$. Also, an unwanted offset introduced in some special situations by the DAE (the so-called "no-fly zone" effect) requires to be handled with great care in order not to introduce systematic effects in the measured signal.

The calibration of the DAE has been performed twice during the CPV, as after the first configuration the LFI calibration team decided to alter the FEM biases of a few channels, therefore changing the absolute level of the signal. This in turns invalidated the first analysis and required us to repeat the process.

The analysis of the two data sets has been discussed in this document. The results can be schematized as follows:

1. Both calibrations have been performed successfully. The procedure developed during the RAA QM/FM tests and the tests at CSL has been consolidated and is now semi-automatic, requiring no more than a few hours to produce a sound calibration table;

2. We have the proof that the "no-fly zone" effect is remarkably stable, as from the analysis of the CPV tests (Summer 2009) we have found the very same results of the RAA FM test campaign (Summer 2006). Also, we finally have the evidence that this effect – which impacts the offset applied to the data – does not depend on the DAE gain.

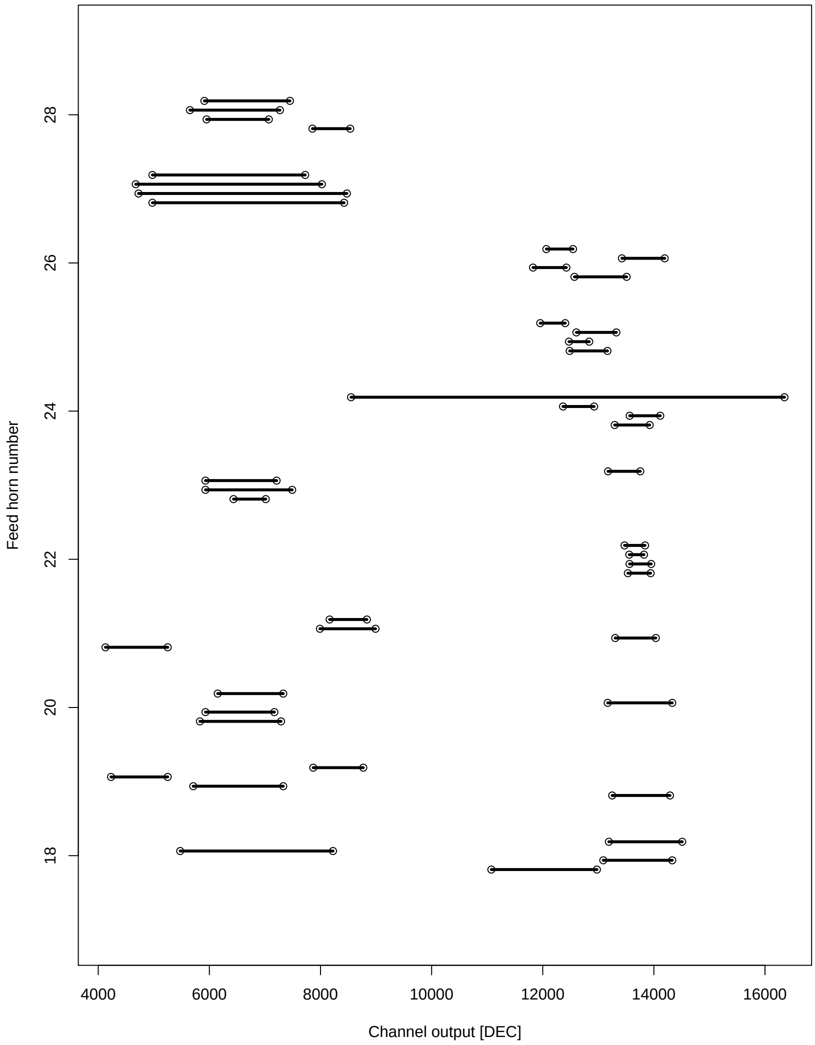

Figure 4: Summary of the verification of the DAE offsets and gains during the First Light Survey (FLS). For each channel the range of DEC values assumed during the FLS are shown as an horizontal bar (only uncompressed data in AVR1 mode are taken into account here, sky and reference samples are both considered). After a saturation in #2411 during the first day (OD91), the extrema of each bars have remained well within the $[0, 16\,383]$ interval. This means that the configuration has put the DAE into a configuration that is stable with respect to the drifts experienced during the FLS.

Channel	**Sky** [V]	**Ref** [V]	**Gain** [DEC]	**Offset** [DEC]
1800	2.52	2.61	1	24
1801	3.30	3.45	0	24
1810	2.03	2.18	1	120
1811	1.68	1.75	1	140
1900	1.37	1.41	9	144
1901	1.47	1.54	9	132
1910	1.05	1.11	9	160
1911	1.33	1.38	9	148
2000	1.91	1.99	9	87
2001	1.90	1.96	9	89
2010	1.37	1.41	2	120
2011	1.37	1.41	2	120
2100	1.07	1.13	9	165
2101	1.04	1.08	9	160
2110	1.01	1.05	2	154
2111	1.01	1.03	2	154
2200	1.32	1.35	9	130
2201	1.32	1.34	9	130
2210	1.21	1.21	9	163
2211	1.46	1.45	9	130
2300	1.33	1.42	9	146
2301	1.76	1.78	9	100
2310	2.58	2.67	8	40
2311	1.40	1.45	9	120
2400	0.048	0.053	11	255
2401	0.049	0.054	4	255
2410	0.075	0.082	4	255
2411	0.080	0.089	4	255
2500	0.098	0.120	10	255
2501	0.093	0.117	10	255
2510	0.073	0.087	10	255
2511	0.065	0.078	10	255
2600	0.075	0.089	4	255
2601	0.090	0.108	4	255
2610	0.069	0.077	4	250
2611	0.076	0.086	10	255
2700	1.22	1.40	9	143
2701	1.32	1.51	9	132
2710	1.26	1.44	9	138
2711	1.03	1.18	9	160
2800	1.09	1.12	9	160
2801	1.37	1.42	9	134
2810	0.97	1.04	9	160
2811	0.84	0.92	9	160

Table 3: Table of the best parameters extracted from the first calibration run (OD61). This table has been discarded when table 4 has been produced a few days after.

Channel	Sky [V]	Ref [V]	Gain [DEC]	Offset [DEC]
1800	2.15	2.23	2	63
1801	2.83	2.94	1	53
1810	1.71	1.84	9	65
1811	1.45	1.51	9	135
1900	1.35	1.40	9	146
1901	1.45	1.53	9	94
1910	0.85	0.90	9	147
1911	1.06	1.10	9	146
2000	1.59	1.66	9	80
2001	1.58	1.63	9	82
2010	1.49	1.54	9	132
2011	1.48	1.53	9	93
2100	0.83	0.88	9	149
2101	0.79	0.82	9	204
2110	0.98	1.01	9	155
2111	0.97	1.00	9	156
2200	0.56	0.57	9	229
2201	0.61	0.62	9	224
2210	0.62	0.63	9	223
2211	0.79	0.79	9	206
2300	1.00	1.01	9	144
2301	1.19	1.25	9	122
2310	1.12	1.17	9	130
2311	0.60	0.62	9	224
2400	0.084	0.092	11	255
2401	0.087	0.094	11	255
2410	0.130	0.144	10	255
2411	0.141	0.151	10	255
2500	0.190	0.220	3	255
2501	0.190	0.200	3	255
2510	0.190	0.220	3	255
2511	0.170	0.190	3	255
2600	0.134	0.159	10	255
2601	0.165	0.189	3	255
2610	0.158	0.178	10	255
2611	0.171	0.189	3	255
2700	1.23	1.41	9	112
2701	1.33	1.53	9	100
2710	1.28	1.47	9	106
2711	1.04	1.20	9	132
2800	1.13	1.16	9	139
2801	1.42	1.48	9	98
2810	1.03	1.11	9	137
2811	0.89	0.97	9	152

Table 4: Table of the best parameters extracted from the second calibration run (OD74). These are the parameters used during the FLS and the subsequent nominal operations.

Channel	V_1^g	V_2^g	V^d	I_1	I_2	PS pos	4kHz	i_d [mA]
18 M1	195	189	126	255	255	1	0	13.7
18 M2	198	201	125	255	255	0	1	15.0
18 S1	155	215	138	255	255	0	1	16.5
18 S2	216	182	114	255	255	1	0	19.0
19 M1	205	221	124	255	255	1	0	20.2
19 M2	196	216	126	255	255	0	1	19.6
19 S1	202	226	120	255	255	0	1	18.2
19 S2	207	222	125	255	255	1	0	18.0
20 M1	191	244	121	255	255	1	0	21.3
20 M2	209	231	127	255	255	0	1	21.3
20 S1	179	230	132	255	255	0	1	17.6
20 S2	169	215	127	255	255	1	0	16.9
21 M1	192	231	147	255	255	1	0	21.5
21 M2	191	224	136	255	255	0	1	23.6
21 S1	170	221	136	255	255	0	1	19.2
21 S2	205	243	132	255	255	1	0	22.1
22 M1	208	218	130	255	255	1	0	18.7
22 M2	188	188	135	255	255	0	1	18.6
22 S1	210	221	128	255	255	0	1	21.2
22 S2	193	231	130	255	255	1	0	18.9
23 M1	211	206	120	255	255	1	1	17.3
23 M2	190	228	119	255	255	1	0	17.6
23 S1	180	222	123	255	255	1	0	21.9
23 S2	198	213	127	255	255	1	1	17.8
24 M1	219	204	183	98	215	0	1	7.3
24 M2	227	204	183	77	185	0	0	7.1
24 S1	218	207	157	84	235	0	1	8.2
24 S2	225	208	152	86	205	0	0	7.7
25 M1	231	203	177	154	245	0	0	6.3
25 M2	218	200	178	79	255	0	1	6.3
25 S1	231	196	167	79	205	0	0	6.1
25 S2	223	199	166	119	225	0	1	6.0
26 M1	247	203	169	108	255	0	1	8.1
26 M2	226	200	170	153	165	0	0	8.4
26 S1	227	194	172	135	235	0	1	6.5
26 S2	240	197	169	93	225	0	0	6.2
27 M1	242	97	156	148	220	0	0	8.0
27 M2	255	96	157	145	205	0	1	7.5
27 S1	235	86	157	127	184	0	0	8.2
27 S2	248	113	156	148	195	0	1	8.0
28 M1	243	101	150	130	160	1	0	9.0
28 M2	240	112	163	127	228	0	1	9.8
28 S1	235	81	157	127	222	1	0	8.8
28 S2	249	90	158	103	165	0	1	9.4

Table 5: Biases used during the first DAE calibration (OD61).

Channel	V_1^g	V_2^g	V^d	I_1	I_2	PS pos	4kHz	i_d [mA]
18 M1	195	189	126	255	255	1	0	13.16
18 M2	198	201	125	255	255	0	1	14.41
18 S1	155	215	138	255	255	0	1	15.91
18 S2	216	182	114	255	255	1	0	18.46
19 M1	213	206	124	255	255	1	0	18.21
19 M2	211	208	126	255	255	0	1	19.93
19 S1	215	209	120	255	255	0	1	17.93
19 S2	204	216	125	255	255	1	0	17.04
20 M1	209	219	121	255	255	1	0	20.66
20 M2	215	221	127	255	255	0	1	20.65
20 S1	199	221	132	255	255	0	1	18.84
20 S2	188	201	127	255	255	1	0	18.64
21 M1	198	207	141	255	255	1	0	18.47
21 M2	196	197	136	255	255	0	1	19.47
21 S1	170	221	136	255	255	0	1	19.11
21 S2	205	243	132	255	255	1	0	22.04
22 M1	203	194	125	255	255	1	0	14.07
22 M2	178	176	130	255	255	0	1	14.84
22 S1	204	189	128	255	255	0	1	16.38
22 S2	206	204	130	255	255	1	0	15.13
23 M1	207	192	120	255	255	1	1	14.72
23 M2	210	195	119	255	255	0	0	14.22
23 S1	181	211	118	255	255	0	0	20.58
23 S2	190	208	122	255	255	1	1	14.76
24 M1	225	225	191	205	205	0	1	16.49
24 M2	225	225	185	205	206	0	0	14.96
24 S1	225	225	158	205	205	0	1	15.53
24 S2	225	225	159	205	205	0	0	16.42
25 M1	225	225	185	205	205	0	0	14.33
25 M2	225	225	187	205	205	0	1	14.83
25 S1	225	225	169	205	205	0	0	14.78
25 S2	225	225	167	205	205	0	1	14.63
26 M1	225	225	176	205	205	0	1	12.84
26 M2	225	225	178	205	205	0	0	14.72
26 S1	225	225	178	205	205	0	1	13.71
26 S2	225	225	176	205	205	0	0	13.38
27 M1	240	108	156	148	220	0	0	8.12
27 M2	244	90	157	145	205	0	1	7.22
27 S1	237	102	157	127	184	0	0	8.45
27 S2	246	114	156	148	195	0	1	8.00
28 M1	243	101	157	130	160	1	0	9.64
28 M2	240	112	156	127	228	0	1	9.19
28 S1	240	84	157	127	222	1	0	9.12
28 S2	245	121	158	103	165	0	1	10.49

Table 6: Biases used during the second DAE calibration (OD74). These are the biases currently loaded into LFI.