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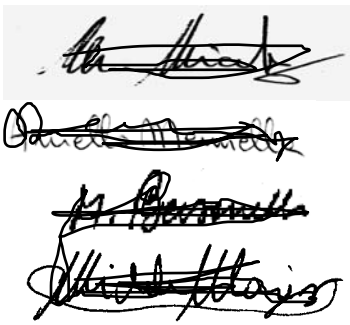
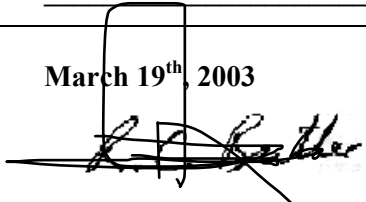
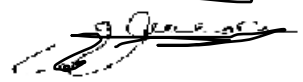
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Abstract

In this technical note we propose a reconfiguration of the LFI on-board data processing and scientific telemetry following the new baseline design of the LFI instrument without the 100 GHz radiometer chains. The proposed strategy uses part of the telemetry resources liberated by the removal of the 100 GHz channel to download the total power radiometer data for all the channels, thus avoiding the on-board differencing between the sky and reference load data that was introduced to comply with the LFI telemetry budget. We show that the proposed new scheme is compatible with the available telemetry and can be implemented with minimal impact on the on-board and on-ground data processing. Furthermore it relaxes some criticalities in the DPC-MOC-satellite communication and improves the LFI instrument monitoring and systematic error control.

1 Introduction

The present baseline design of the Planck-LFI instrument does not foresee any longer the presence of the 100 GHz channel. An optimization process is currently underway in the LFI instrument team to optimize the re-use of the LFI resources (i.e. power, mass, telemetry, etc.) in order to remove criticalities and to reduce programmatic and performance risks. This note concerns the reconfiguration of the telemetry resources.

In presence of the 100 GHz array in LFI, in order to maintain the telemetry budget, it was necessary to reduce the data rate by a factor of 2 by performing on-board differences between the sky and the reference load signals of each channel. To achieve this, a scheme was designed that required on-ground calculation of a parameter, the so-called gain modulation factor, to be used in the on-board differencing. The value of this parameter is crucial to meet the $1/f$ noise requirements, and it would be monitored and regularly updated during the Planck survey. The optimized value of the gain modulation factor for each radiometer would be calculated using a limited portion of the total power data (about 15 minutes per day), to be downloaded uncompressed together with the compressed differenced radiometer data [1, 2].

In this document we propose to download the total power radiometer data (i.e. sky and load data streams separately) for the descoped LFI, thus eliminating the above mentioned criticality. In particular, the proposed scheme eliminates the need to keep the value of the gain modulation factor updated on the satellite, therefore eliminating the need of a fast loopback between MOC, DPC and the satellite. We show that the new proposed approach fits comfortably within the telemetry resources that have been liberated by the removal of the 100 GHz channel, and it can be implemented with minimal modifications to the current data processing software (both on-board and ground). The proposed solution also offers a more effective monitoring of the instrumental noise properties and a stronger diagnostic power on potential systematic effects.

1.1 Telemetry Resources

In this section we present the current LFI telemetry budget which is consistent with the previous instrument baseline that included the 100GHz chains. According to this budget the allocated resources for LFI are a total of 54kbps (averaged on one day). These are then subdivided internally in about 2.5kbps for HK and the



remaining 51.5kbps for science TM. Both these figures include margins especially for science data that rely on the achievable compression rate.

The following table reports the current budget for scientific telemetry considering the presence of 100 GHz LFI radiometers.

	30 GHz	44 GHz	70 GHz	100 GHz	Total
Horns	2	3	6	12	
Radiometers	4	6	12	24	
Detectors chains	8	12	24	48	92
Angular resolution (arcmin)	33	23	14	10	
Samples per beam	3				
Samples per second (word/s)	33	47	77	108	
Word length (bit)	16				
Total frequency data rate (kbps)	4.17	8.98	29.51	82.63	125.29
Compression factor	3.8				
Net scientific data volume (kbps)	1.10	2.36	7.77	21.74	32.97
Packet frequency radiometer (Hz)	0.140	0.300	0.987	2.762	4.188

Table 1: Scientific telemetry budget in the old LFI configuration (with 100 GHz radiometers)

In the baseline on-board data processing (consistent with the budget in Table 1) the sky and reference load data samples are differenced on-board using the so-called *gain modulation factor*, r , to cancel most of the $1/f$ noise present in the total power data [2].

The optimisation of this factor is crucial to meet the radiometer noise performance requirements; the calculation of the optimal r is performed on ground from short sections of data in total power mode (processing type 1 not considered in the table) and updated on the satellite by telemetry if necessary. This scheme, that was chosen to comply with the telemetry requirements, presents the following disadvantages:

1. an efficient ground-segment loop is necessary to ensure that an optimal value of r is always used on-board. Furthermore the time-lag of about three days between the time data are received on ground and the time the value of r can be updated by telemetry will require extrapolation to compensate for slow drift in noise performances during this lag;
2. most of the total power data from the radiometers will not be available on ground because of the on-board differencing; these data would be extremely useful to monitor the radiometer noise performances over time and to optimise the systematic error analysis.

From the data shown in Table 1 it is apparent that in the new LFI baseline (i.e. without the 100 GHz channel) with the current data processing scheme a large fraction of the available TM remains unused. In this



document we propose a modification in the on-board data processing scheme that uses part of the liberated telemetry resources to download the total power radiometer data in order to remove the criticalities on the ground segment linked to the updating of r and optimise the control on instrumental systematic errors.

The scientific data rate budget that is obtained considering this modification is shown in Table 2. Note that the required compression factor has been relaxed from 3.8 to 2.4 and that no calibration channel is considered here.

	30 GHz	44 GHz	70 GHz		Total
Horns	2	3	6		
Radiometers	4	6	12		
Detectors chains	8	12	24		44
Angular resolution (arcmin)	33	23	14		
Samples per beam	3				
Samples per second (word/s)	66	94	154		
Word length (bit)	16				
Total frequency data rate (kbps)	8.35	17.96	59.02		85.33
Compression factor	2.4				
Net scientific data volume (kbps)	3.478	7.484	24.592		35.554
Packet frequency radiometer (Hz)	0.442	0.951	3.124		4.516

Table 2: Scientific data rate with the proposed baseline modification configuration

1.2 Options

In the new baseline configuration of the LFI instrument we can identify two options concerning the LFI on board data processing and the scientific telemetry budget: (i) maintain the baseline data processing scheme and (ii) modify the on-board data processing in order to downlink the total power radiometric data for all the channels. In this section we discuss the various implications of the two possibilities and present some possible implementations of the second option

1. **Maintain current baseline:** nothing changes except the number of channels to be downloaded.

Advantages: no impact on flight and ground SW and data processing

Disadvantages:



- Efficient loop is needed between ground segment and satellite to update the r parameter.
- The value of the r parameter calculated on ground needs to be extrapolated at the time it is uploaded to the satellite
- Most of the total power information of the radiometer data is not available on ground

2. **Modify current baseline to allow downlink of total power data for all channels**: change the on-board processing to avoid the on board differences and sends to ground the sky and reference data stream. This possibility could be obtained with modifications of both flight and ground SW in different ways.

2.1 Send sky and reference load values in the same data packet: the two data streams are put in the same packet arranging alternatively sky and data words. This produces values of the samples widely separated within the input range of the compressor therefore two different set of parameters (quantisation step and offset) ¹ are needed for the second quantisation process in order to achieve a useful compression rate.

Advantages compared to baseline:

- The need for a fast response to keep the r parameter on board optimised is eliminated.
- The need to extrapolate the value of r calculated on ground to match the instrumental conditions at the time of upload is eliminated.
- The availability of sky and reference load data on ground will enhance the control on systematic effects and the instrument monitoring capabilities.

Disadvantages compared to baseline:

- Flight SW changes for the processing and the construction of TM packets.
- The high level of $1/f$ noise in the total power data streams may degrade the compressor performances.
- The ground SW needs to be modified to be able to use the new scientific packet formats

2.2 Send sky and reference load values in separated packets: the two data stream are separated in two packet streams each containing respectively only sky and only reference data. In this way the sky

¹ The second quantisation of a sample X consists of the application of the following operator mapping a float X in a 16 bits integer x : $x = \Theta[(X - O) / q]$. Where O represents an offset used to keep the distribution of quantised samples in a packet within the range of values for the 16 bits integer, q is the quantisation step (or gain) chosen keeping constant the ratio σ/q where σ is the rms of X , $\Theta[.]$ represents a truncation or rounding operator. The couple of parameters (O, q) are downloaded to ground together with the data in the packets to allow reconstruction of data.



and load samples remains uncorrelated and could be matched again only by means of their times.

Advantages compared to baseline: as in point 2.1

Disadvantages compared to baseline:

- As in point 2.1, plus
- The ground SW must be able to correlate each sky data sample with the corresponding reference load data sample that will be received in a different packet

2.3 *Send a linear combination of sky and reference load values:* for each couple of sky and load data two new values are calculated using two independent linear combinations so to cancel most of the offset and $1/f$ noise present in the original total power data, which are reconstructed on ground using the same parameters used on board. With this scheme the on-board data processing remains mainly unchanged; the only modification is that for each couple of sky-load data two combinations will be computed instead of one. Furthermore the low $1/f$ noise present in the data that will be sent to the compressor guarantees that the compression rate will not be degraded significantly by adopting this new scheme.

Advantages compared to baseline: as in point 2.1

Disadvantages compared to baseline:

- Change in the on-board SW in order to calculate two linear combinations for each sky-load couple instead of one
- Change in the ground SW to reconstruct the total power data from the science telemetry data and the linear combination parameters

As outlined above, option 2.3 appears to be the most promising to optimise the use of the available telemetry and remove the criticality imposed by the need to update r while minimizing the impact on the ground and on-board data processing. This option is presented and discussed in more detail in the following sections



2 Proposed solution

2.1 Strategy

In the baseline data processing each couple of sky and reference load data samples, $T_{\text{sky}}, T_{\text{ref}}$ ², are differenced using a so-called *gain modulation factor* that balances the output and reduces the $1/f$ noise to very low levels. In particular each data sample sent to ground has the form $p_0 = G(T_{\text{sky}} - r_0 \times T_{\text{ref}})$, where G is the radiometer gain, T_{noise} represents the noise temperature and $r_0 \approx T_{\text{sky}} / T_{\text{ref}}$. The parameter r_0 is calculated on ground using short sections of total power data which are downloaded uncompressed for each channel. With this scheme the information concerning the total power data is lost.

In the proposed new scheme we adopt a very similar procedure where for each sky-reference couple we compute the following linear combinations:

$$\begin{aligned} p_1 &= G(T_{\text{sky}} - r_1 \times T_{\text{ref}}) \\ p_2 &= G(T_{\text{sky}} - r_2 \times T_{\text{ref}}) \end{aligned} \quad (1)$$

with r_1 and r_2 being two fixed parameters around the value of 1 with $r_1 * r_2 \neq 1$. Note that these parameters (which need not to be optimized) will eliminate the great majority of the offset and of the $1/f$ noise leaving two almost white data streams, which implies a negligible impact on the compressor performances.

By knowing the parameters r_1 and r_2 it is possible to reconstruct the total power data on ground from:

$$\begin{aligned} G \times T_{\text{sky}} &= \frac{p_2 r_1 - p_1 r_2}{r_1 - r_2} \\ G \times T_{\text{ref}} &= \frac{p_2 - p_1}{r_1 - r_2} \end{aligned} \quad (2)$$

provided that $r_1 - r_2 \neq 0$.

With this scheme the data stream sent to the compressor is characterized by a small amount of $1/f$ noise; furthermore the consecutive samples have about the same value and variance limited to a few samples around the mean value.

In the next section we provide some examples with simulated data streams of the application of this scheme compared to the baseline.

² Note that the sky and reference data samples are of the form: $T_{\text{sky(ref)}} = \tilde{T}_{\text{sky(ref)}} + T_{\text{noise}}$ where $\tilde{T}_{\text{sky(ref)}}$ represents the signal and T_{noise} the radiometer noise temperature



2.2 Verification

To verify the feasibility of such scheme and to compare it to the baseline for what concerns the quantisation error we have considered the two total power data streams shown in the following figure, which are representative of the radiometer output at 30 GHz:

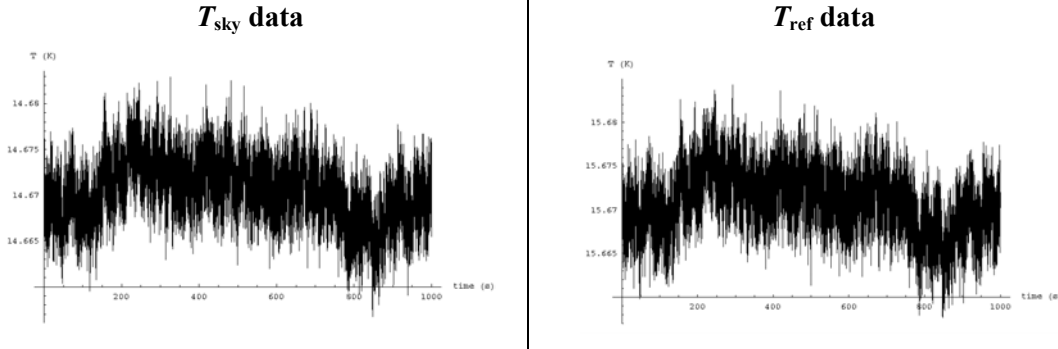


Figure 1: Total power simulated data used in the calculation

To check the two schemes we have performed the calculations according to the various steps outlined below:

Baseline scheme:

1. calculate r_0 from the ratio of the average values of the total power streams;
2. calculate the differenced data stream $p = T_{\text{sky}} - r_0 \times T_{\text{ref}}$;
3. calculate the average and rms values of the differenced data stream, T_{ave} , σ ;
4. calculate the quantisation step as $q = \sigma / 2$;
5. quantise and round the differenced stream according to $p_q = (p - T_{\text{ave}}) / q$;
6. reconstruct the differenced stream according to $p_{qr} = p_q \times q + T_{\text{ave}}$
7. evaluate the difference between the original and reconstructed differenced data streams, $\mathcal{E}_q = p_{qr} - p$ (peak to peak and rms value).

New proposed scheme:

1. fix two values of r_1 and r_2 around 1 (we chose $r_1 = 1$ and $r_2 = 0.85$);
2. calculate the linear combinations p_1 and p_2 according to Eq. (1)
3. calculate the average and rms values of the two linear combinations p_1 and p_2 ($T_{\text{ave},1}$, $T_{\text{ave},2}$, σ_1 , σ_2);
4. calculate the two quantisation steps as $q_{1(2)} = \sigma_{1(2)} / 2$;
5. quantise and round the differenced streams according to $p_{1(2)q} = (p_{1(2)} - T_{\text{ave},1(2)}) / q_{1(2)}$;
6. reconstruct the differenced streams according to $p_{1(2)qr} = p_{1(2)q} \times q_{1(2)} + T_{\text{ave},1(2)}$
7. reconstruct the total power streams, $T_{\text{sky},qr}$, $T_{\text{ref},qr}$, from using Eq. (2) with p_{1q} and p_{2q} ;



8. calculate $r_{0,qr}$ from the ratio of the average values of the reconstructed total power streams;
9. calculate the differenced data stream $\tilde{p}_{qr} = T_{sky,qr} - r_{0,qr} \times T_{ref,qr}$;
10. evaluate the difference between the original and reconstructed differenced data streams,
 $\tilde{\varepsilon} = \tilde{p}_{qr} - p$.

In the next figure we show two plots representing the quantisation errors ε and $\tilde{\varepsilon}$ for the two data processing schemes. The two figures clearly show that the new processing is able to reconstruct the total power data and the final differenced data stream with an accuracy which is comparable (actually slightly better) with the baseline processing.

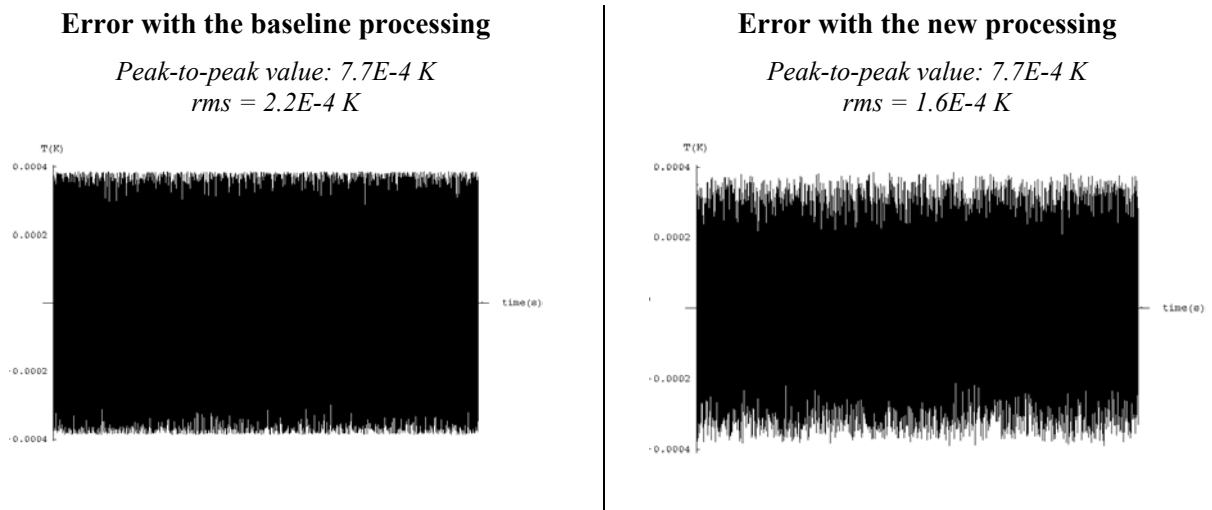


Figure 2: comparison of the errors obtained with the baseline and new on board data processing. The two approaches yield essentially similar results (in the new processing scheme the rms value of the final error is slightly less compared to the baseline)

3 Implications

Although this new data processing scheme can be implemented with minor impact on the on-board and ground data analysis, there are some implications that are worth mentioning

3.1 Implications on the on-board SW:

The effects of the described modification on the REBA application software (ASW) will be the following:

- The processing type 5 will become the default processing type and will be modified according to the described formulas implementing the two differences with the parameters r_1 and r_2 . The second quantisation remains as before.



- It is needed an additional TC(8,4) (or a modified one) to upload the new parameters for the processing.
- It is needed a slight modification of a diagnostic HK packet and the science TM packet to include the second factor r parameter.

3.2 Implications on the MOC activities

The adoption of this alternative data processing scheme will have a positive impact on the MOC activities as it will avoid the necessity of a fast loop-back between Satellite-MOC-DPC in order to update the gain modulation factor in the shortest possible timeframe.

In fact to allow a change of r in flight a specific set of telecommands, and a specific set of confirmation/rejection/failure messages, have to be defined and implemented. The timing of the execution of the telecommands operating the change in r need to be carefully monitored, in order to allow the DPC to know from when the new r value has been applied to data.

To have a fast determination of r the DPC will have to perform the determination as soon as it receives the related diagnostic scientific packets. This implies a complex sequence of operations to be performed for each radiometer (open the packets, determine the noise statistic, determine the new r value, discuss them with the instrument operations team, prepare a table of actions to be submitted to MOC, submit them the MOC waiting for the execution of such actions or for some error message from the MOC). At the same time the MOC will have to be prompt in scheduling the new actions (whose occurrence and rate is in itself unpredictable), checking for formal errors and executing them. For each of these steps appropriate procedures need to be planned, tested and documented.

3.3 Implication of the DPC activities

This new data processing will increase slightly the workload of Level 1 of the DPC because the sky and load data will have to be differenced on ground. Furthermore slight modifications in the code for the Quick Look Analysis and in the interface with the data base (DMCI).

However, the possibility to receive undifferentiated data will reduce the criticality of some DPC operations, as the r determination and correction. Leading to the possibility to recover from errors or to repeat the data reduction from scratch in the case a better procedure is identified to determine r . Moreover the DPC will receive a more homogeneous set of data than the current baseline, where packets with differentiated data are mixed with packets of diagnostic scientific undifferentiated data which have to be managed by a specific part of the pipeline. In addition DPC will not need to manage telecommand confirmation messages in order to know when a specific r value has been replaced by a new one.

4 References

- [1] A. Mennella, and M. Bersanelli, "Measurement of the gain modulation factor during the LFI sky survey", PL-LFI-PST-TN-032, May 2002
- [2] M. Miccolis "Communication ICD" PL-LFI-PST-ID-013, Issue 2