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TITLE: **Planck/LFI: Weak Signals, RON and DAE/REBA Calibration**

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CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
0	2008 Mar 21		Starting of the document	0
1	2008 Apr 1		First Issue	0

1 SCOPE

This document is a first assessment of the following two problems:

1. impact of RON on measures of signals of low amplitude at PLANCK/LFI;
2. constraints on DAE calibration from REBA calibration for low amplitude signals.

1.1 LIMITS OF APPLICABILITY

This document applies just at PLANCK/LFI.

2 APPLICABLE/REFERENCE DOCUMENTS

2.1 APPLICABLE DOCUMENTS

[AD-1] Planck/LFI Communications
M.Miccolis
PL-LFI-PST-ID-013, V3.1, Nov. 2004

2.2 REFERENCE DOCUMENTS

[RD–1] *The effect of signal digitisation in CMB experiments*
M. Maris, D. Maino, C. Burigana, A. Mennella, M. Bersanelli and F. Pasian
A&A 414, 777-794 (2004)

2.3 ACRONYMS LIST

ADU	Analog Digital Unit
DAE	Digital Acquisition Electronics
LSB	Least Significant Bit
REBA	Radiometer Electronics Box Assembly (LFI)
RON	Read Out Noise
TQL	Telemetry Quick-Look

3 OVERVIEW

During the ground test campaign it has been observed that in some conditions the RMS of radiometer output, after the first steps of acquisition, Digital to Analog Conversion, REBA acquisition and on-board averaging [AD-1] is quite small, being of the order of 1 ADU.

A so low level of rms affects the way in which the subsequent steps in the on-board processing (mixing, requantization and compression) could be applied without to introduce a too large distortion in the data. In addition a low level of rms implies that the RON from the ADC could affect in a significant manner the estimate of the noise properties of the radiometers.

4 IMPACT OF RON

Read Out Noise, RON, for and ADC comes from two sources of perturbation

1. the ADC quantization;
2. the ADC noise.

both of them being proportional to the adc quantization step, q_{adc}, which by definition it is assumed to take the value of 1 ADU or, in volts, is given by (Vmax - Vmin)/2^{14}, where [Vmin, Vmax] is the range of allowed ADC voltages in input.

We recall that each LFI sample, following the on—board processing in [AD1], is the average of *N*aver samples, after that the effective resolution in ADU will be improved of a factor $1/\sqrt{N\text{aver}}$.

The effect of ADC quantization is to add a non--gaussian noise to the signals with rms $1/\sqrt{12}$ before averaging and $1/\sqrt{(12\ N\text{aver})}$ after averaging.

In addition the ADC itself has a random read-out noise about σ_{adc} ADU which after averaging is reduced to $\sigma_{adc}/\sqrt{N\text{aver}}$ and which adds in quadrature with the quantization noise making the ReadOut Noise (RON) whose rms is $\sigma_{RON} = \sqrt{(1/12 + \sigma_{adc}^2)}$ before averaging and it is scaled by the usual $1/\sqrt{N\text{aver}}$ factor after averaging. Given the 1/12 factor in front of the variance induced by the ADC contribution, the random noise in the ADC could be principal source of RON when $\sigma_{adc} > 0.3$.

When a signal of rms σ_0 is measured by the DAE a gain, *G,* is applied and the measured rms is

$$\sigma = \sqrt{(\sigma_{RON}^2 + G^2\sigma_0^2)} \qquad (1)$$

depending on the ratio $\sigma_{RON}/G\sigma_0$ the measured rms will be dominated by the ADC noise or by the signal rms.

We define small signals, those signals whose RMS is comparable to the read--out noise.

Of course in the case of small signals the read--out noise has to be considered when, as an example, the σ_0 has to be measured in order to estimate, as an example, quantities such as the Tsys. The same when the variation of the rms of the signal tacking in account of variations of *G* has to be estimated.

Some tests gives $0.4 < \sigma_{RON} < 0.9$ with median $\sigma_{RON} \sim 0.57$, if $\sigma_0 \sim 1$ the bias in estimating σ_0 will be ~ 15%.

5 DAE AND REBA TUNING

In designing and optimizing the REBA processing it has been assumed that hallways the rms of the data in output to the requantization and compression stages would have to be of the order of several ADUs. Indeed the rms of any of the two linear combinations P1, P2 before second quantization is applied is

$$\sigma_i = \sqrt{(\sigma_{\text{load}}^2\, r_i^2 - 2 r_i \sigma_{\text{sky,load}} + \sigma_{\text{sky}}^2)},\ \ i=1,2; \qquad (2)$$

where σ_{sky}, σ_{load} ,and $\sigma_{\text{sky,load}}$ are respectively the rms of sky, reference-load and their covariance, AFTER the averaging step, while r_1 and r_2 are the mixing parameters or gain modulation factors.

The problem is to asses both σ_i to be larger than a minimal σ_{tgt} , typically assumed to be in the range 2 ADU – 16 ADU for a suitable range of r_1 and r_2 values.

From this equation it is evident that the σ_i^2 as a function of r_i defines two identical concave parabolas with a minimum in

$$r_1 = r_2 = r_{\text{min}} = \sigma_{\text{sky,load}}/\sigma_{\text{load}}^2, \qquad (3)$$

with the σ_i in the minimum taking the value

$$\sigma_{\text{min}} = \sigma_{\text{sky}}\sqrt{(1-\rho_{\text{sky,load}}^2)}, \qquad (4)$$

where $\rho_{\text{sky,load}}$ is the correlation coefficient between sky and load. Note that $\sigma_{\text{min}} = 0$ in the case of a perfect correlation among sky and load.

So a sufficient condition to asses proper DAE calibration is

$$\sigma_{\text{tgt}} = \sigma_{\text{sky}}\sqrt{(1-\rho_{\text{sky,load}}^2)}, \qquad (5)$$

which puts a constrain on the minimum ratio $G/\sqrt{N}$aver.

In particular assuming that the RON is small with respect to the sky and load rms, at first order

$$G/\sqrt{N}\text{aver} > \sigma_{\text{tgt}}/\sigma_{\text{sky,0}}\sqrt{(1-\rho_{\text{sky,load}}^2)}, \qquad (6)$$

where $\sigma_{\text{sky,0}}$ is the sky rms which would have been measured with G=1, no averaging and null RON.

It could happen that in some cases the condition (5) could be not full-filled for any reasonable value of G and Naver. So a *forbidden region* in the r_1, r_2 space is defined by imposing

$$\sigma_1 < \sigma_{tgt} \wedge \sigma_2 < \sigma_{tgt} \qquad (7)$$

This defines a cross shaped region, whose center is defined by Eq.(3), shown by Fig. 1, with harms parallel to the axis and width of each harm Δr given by

$$\Delta r = 2\,(\sigma_{sky}/\sigma_{load})\sqrt{[(\sigma_{sky}/\sigma_{load})^2 - (1-\rho_{sky,load}^2)]}, \qquad (8)$$

Hence, DAE calibrators could monitor the evolution of Δr as $G/\sqrt{N}$aver varies during DAE calibration in order to keep it within safe limits.

In general the optimization of r_1, r_2 is performed over a limited rectangular region of space. Then an informative parameter would be the fraction of area of the region of interest excluded by the DAE calibration, $f_{DAE,excl}$.

It is not possible to write a general formula for $f_{DAE,excl}$ valid for all the possible cases but if $\rho_{sky,load}^2$ is small, the excluded region has center near $r_1 = r_2 = 0$, and if while optimization region is squared and has centre in the origin, i.e. $-r_{lim} < r_1, r_2 < +r_{lim}$, in that case

$$f_{DAE,excl} = [(4r_{lim} - \Delta r)\Delta r]/(4r_{lim}^2). \qquad (9)$$

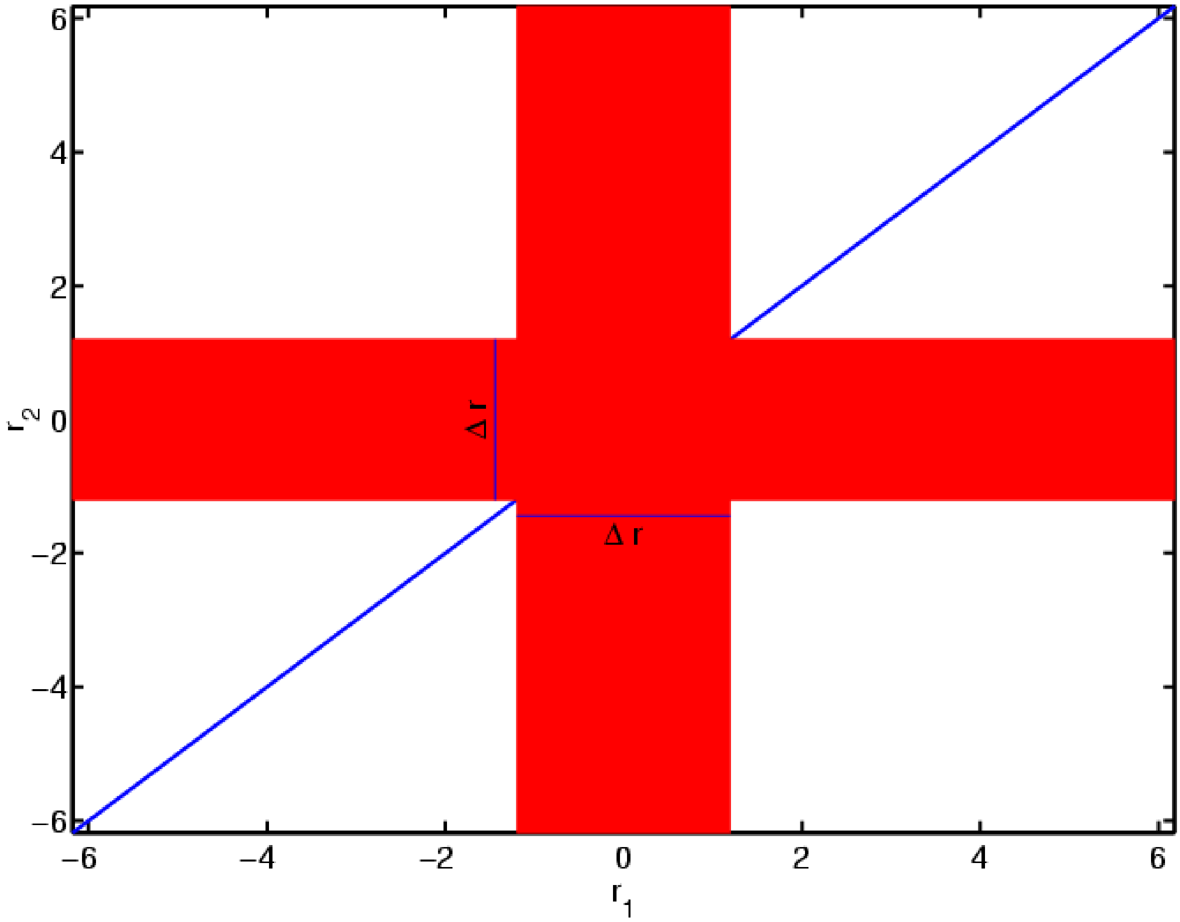

Fig.1 The red area is the region of the r1, r2 space excluded by the condition σ_1 and $\sigma_2 < \sigma_{tgt}$. The width of the two crossing bands, Δr, is given by Eq.~(8) and in this case $f_{DAE,excl}$ ~ 0.35.

6 REQUIREMENTS FOR A DAE TUNING TOOL ON THE TQL

Hence DAE tuning has to assure sufficiently large σ_1 , σ_2 by tuning G and Naver.

In this respect it would be desiderable to add a monitor tool in the TQL toolbox allowing to plot for each detector σ_{min}, Δr versus σ_{tgt} and and $f_{DAE,excl}$.

The tool would allow for each detector under testing:

1. to fix a time interval τ, of about 10 sec – 30 sec;
2. to fix a $r1$, $r2$ interval;
3. to evaluate for the input signal, within each time interval τ: σ_{sky}, σ_{load}, $\rho_{sky,load}$;
4. from these quantities to evaluate Δr, σ_{min} and $f_{DAE,excl}$ according to the above equations;
5. to plot as a function of time those quantities.