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1.0	06-02-09		1st issue	

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1 ACRONYMS

AIV	Assembly, Integration, Verification
TBC	To be completed
TBI	To be included

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

[AD 1] PL-LFI-PST-AN-006 , 'Data analysis and scientific performances of the LFI', A. Mennella, M. Bersanelli, B. Cappellini, et al
[AD 2] PL-LFI-PST-TN-084, 'A critical data analysis of the RCA27 Flight Spare Tuning' , L. Terenzi , F.
[AD 3] Cuttaia, S. Grassi
[AD 4] PL-LFI-PST-TN-0X90. 'Matrix Tuning Strategy for CSL' , Cuttaia, Stringhetti
[AD 5] PL-LFI-PST-PL-013, 'Testing Plan of the LFI instrument during the Planck Commissioning and CPV phase' , L. Stringhetti, A. Gregorio, A. Mennella, et al.
[AD 6] PL-LFI-OST-PR-021, TV Tests: LFI Test Under cryogenic Vacuum, L. Stringhetti, A. Gregorio

3 INTRODUCTION

In this memo we describe the proposal for a new tuning bias approach to be applied during the CPV phase. The need of a different approach in bias tuning during CPV compared to what was used during Instrument Level Tests (ILT) has been clear since long, due to the complexity and criticality of the baseline scheme that was, on the other hand, optimal for ILT.

This baseline scheme, currently implemented in CPV timeline which is based on the CPV test plan v. 1.1., foresees two consecutive and dependent tuning steps (Vg1 followed by Vg2) to be performed during the cooldown phase of the 4K cooler. Because each step needs an independent temperature jump, the major criticality of this approach is in the time needed to complete, analyse and set the optimal Vg1 values before starting the Vg2 tuning step in the middle of the 4K cooldown.

It was therefore decided that this approach would be revised after the CSL test campaign, during which a different approach named "matrix tuning" was tested. Here we briefly summarise the lessons learned from CSL and outline a proposal for CPV.

We stress the importance of the tuning phase which is the time in which the noise performances of the instrument are defined. During CPV this will be a decisive phase in which the scientific performances of the LFI will be set for the rest of the mission. It is therefore of key importance that the strategy that will be implemented will guarantee that the optimal point will be recognized and set.

In this document we present a proposal that goes in this direction.

3.1 Acknowledgments

This document has been issued as a part of the activity performed under the ASI contract for Planck phase E2.

4 Matrix tuning and its implementation in CSL

The tuning approach named "matrix tuning" foresees, in its original idea, to operate the radiometer in nominal switching conditions while observing an input source set at two or more stable temperatures. At each temperature a matrix of $N\times N\times N\times N$ bias combinations $[\{V_{g1}^{ACA1}, V_{g2}^{ACA1}\}, \{V_{g1}^{ACA2}, V_{g2}^{ACA2}\}]$ around a starting point (namely the optimal point found during ILT) is commanded and the corresponding voltage output is recorded. For each quadruplet the radiometer noise temperature and isolation is calculated. An optimisation analysis finally returns the bias quadruplet that yields best performances.

Time constraints deriving from the CSL schedule forced us to revise this idea so that a reduced scheme was applied. In this scheme bias values were not changed simultaneously on the two ACAs but according to two 7x7 matrices of $\{V_{g1}, V_{g2}\}$ that were applied consecutively to the two ACAs. The benefit of this approach was evidently a reduction of bias points (and therefore time) from N^4 to $2\times N^2$ that was however obtained at the cost of (i) excluding large bias regions from the performance assessment and (ii) forcing a correlation between noise temperature and isolation (biases on ACA1 are swept with a fixed bias pair on ACA2 and vice versa).

Although the matrix tuning scheme has proved to be a powerful tuning approach, the simplifications adopted in CSL cast doubts that optimal bias quadruplet resulting from tuning analysis could be biased by isolation and, therefore, be representative of a local and not global performance optimisation.

Furthermore the analysis of the CSL data has shown that, in many cases, noise temperature appears to keep decreasing also outside the tested bias window, as shown in the following Figure (relative to LFI24M-11) that shows how noise temperature keeps decreasing also outside the tested bias matrix.

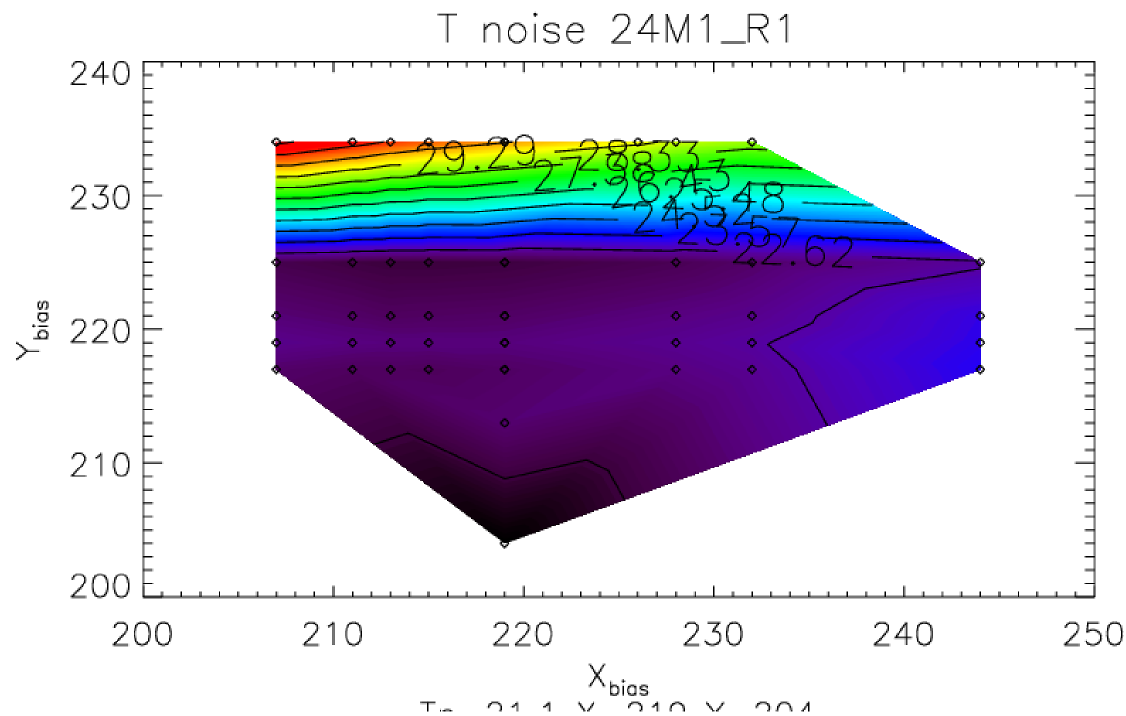


Figure 1

In summary, the lessons learned from the CSL tuning experience can be summarised as follows:

1. The matrix tuning approach is powerful and removes the criticality of the old baseline followed during ILT
2. The matrix decoupling between the biases on the two ACAs reduces the execution time but introduces a bias toward optimal isolation that might drive the system to a local performance optimisation.
3. In some cases best noise performances appear to be located near to the border of the matrix, which suggests the possibility of increasing the tuning performance with an improved strategy in the matrix definition

Furthermore a subsequent analysis of tuning data has demonstrated the possibility to identify at zero order the tuning performances by analysing receiver data acquired when the receivers are unbalanced, with the sky at low temperature (e.g. 2.7 K) and the reference load at 20 K or higher. In the following figure we show the comparison of the tuning surface obtained with this zero-order analysis (left) and the surface obtained analysing the full set of data (right). It is clear that this rough analysis is able to give the idea of how the surface behaves; this opens up the possibility of running a pre-tuning (without the need of a temperature step) aimed at screening the bias space and defining a narrow region where to concentrate the search exploiting the cooldown.

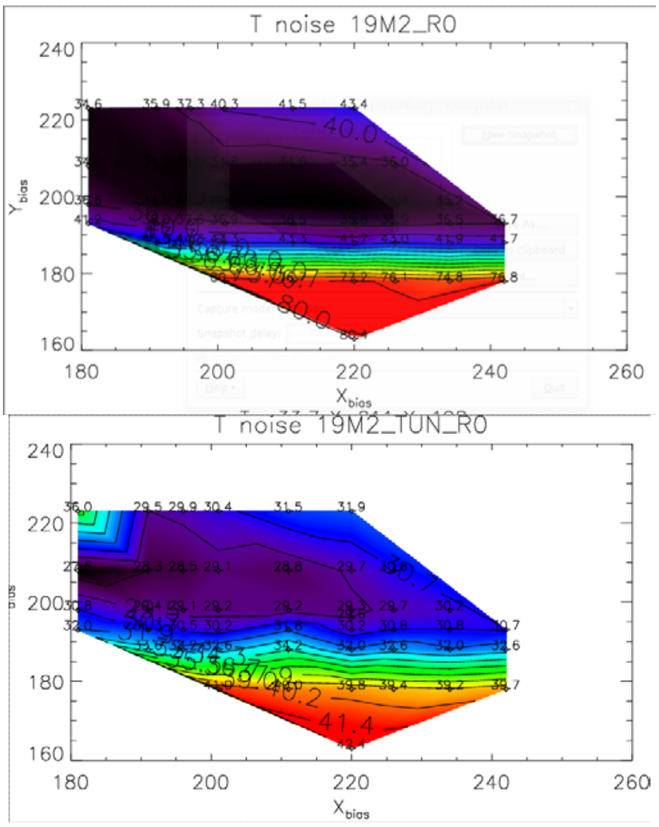


Figure 2

In the following of this document we present a detailed proposal that will exploit this possibility to overcome the limitations of the matrix tuning as implemented in CSL and maximise the effectiveness of this crucial phase for the scientific performance of the LFI.

5 The HYPER MATRIX strategy

This section is dedicated to explain details of the new tuning strategy here proposed, focusing on the scheme of procedure, timeline and main differences with respect to ILT and CSL strategies. More explanations are added in the appendix section.

5.1 GENERAL SCHEME

The Hyper Matrix Tuning (from now on, HMT) is mainly composed by two sections :

a) PRE- TUNING –SCREENINING (PTS) ➔ STEP 0

b) TUNING-RUN (TR) ➔ STEP 1-4

STEP 0

The PTS is a rough investigation devoted to widely screen the range of possible parameters (Vg1 and Vg2 bias) in order to further centre and restrict it around the best expectation point. Input for PTS are the results from CSL test campaign. Output from PTS will be used as input for TR section. Main objective of the PTS is to restrict the bias range for the next TR phase, in order to save time without loosing information. It does not require any changes in Reference Load temperature because it just bases on the unbalancing of sky-ref signal when the radiometer works in switching condition observing thermal loads (namely, ref at 22K, sky at 2.7K)

STEPS 1-4

The TR is devoted to explore the bias range (gate Voltage Vg1, Vg2 and several values of drain voltage Vd) previously individuated by PTS. It is performed over a narrower range: it has a higher sensibility to detect possible absolute minima / maxima. It requires at least two steps in the reference loads temperature (22K, 4.5K), to perform Y-factor analysis; however, because of the non linear behaviour of some LFI radiometers, two more intermediate steps are requested, between 22K and 4.5K.

Here follows an ideal scheme of the HMT flow. It does not take into account the profile of the real cooldown.

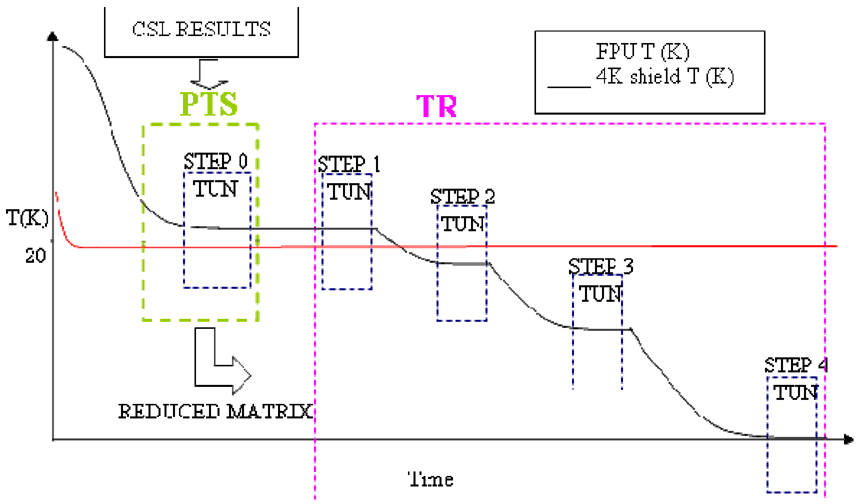


Figure 3 conceptual scheme of Hyper Matrix Tuning strategy: when 4K Reference Load Temperature is about 22K a pre hyper-matrix tuning screening (PTS) is performed starting from CSL results. Data analysis provides results to define reduced matrixes to be used as input for Hyper Matrix Tuning Run (TR). TR is performed running the same procedure and values over 4 temperature steps.

5.2 PROCEDURE AND REQUIREMENTS

5.2.1 Channels Groups (parallelization)

Channels to be operated are grouped in order that bias changes over one channel do not interfere with any others' behaviour. The same grouping criteria are used for all the STEPS.

During CSL Tests changes have been operated over 6 groups. Results from CSL analysis show the possibility to reduce to 4 groups, in the case it was helpful to save time. It looks not feasible to run the procedure parallelized over more channels. (The interference table is shown in APPENDIX 1).

N	CSL GROUPS	CPV GROUPS
1	RCA 18 + RCA 21	RCA 18+ RCA 19 + RCA 22
2	RCA 19 + RCA 22	RCA 20 + RCA 21 + RCA 23
3	RCA 20 + RCA 23	RCA 24 + RCA 26 + RCA 28
4	RCA 25 + RCA 24	RCA 25 + RCA 27
5	RCA 26 + RCA 27	
6	RCA 28	

Table 1 comparison between grouping scheme adopted in CSL Matrix and proposed for CPV Hyper Matrix.

Number of points to be explored

Vg1 and Vg2 will be changed over the same radiometer simultaneously for both ACA1 and ACA 2. For each couple of ACA, but only for steps from 1 to 4, also Vd will be changed (for both ACA1 and ACA2 at the same time) in 3 values, over the best 15 quadruplets coming from STEP 0 HPT analysis (it means 3X3X15 quadruplets , that is 135 points). This part of the proposal is justified in APPENDIX 3.

	ACA1		ACA2				
N	Vg1	Vg2	Vg1	Vg2		Vd1	Vd2
STEP 0	7	4	7	4		NO	NO
STEP 1	5	5	5	5		3	3
STEP 2	5	5	5	5		3	3
STEP 3	5	5	5	5		3	3
STEP 4	5	5	5	5		3	3

Table 2

5.2.2 Integration time per point

During CSL test campaign the integration time was fixed by THASF to 30 seconds for all channels. Here, in order to save time, the maximum allowed (because of thermal drifts on LNAs) time reduction is proposed, depending on channels.

N	CPV GROUPS	Time STEP 0 (s)	Time STEP 1 – 4 (s)	VD change
1	RCA 18+ RCA 19 + RCA 22	14.5	18	20
2	RCA 20 + RCA 21 + RCA 23	14.5	18	20
3	RCA 24 + RCA 26 + RCA 28	9	13	20
4	RCA 25 + RCA 27	9	13	20

Table 3

5.2.3 Thermal requirements

FPU Temperature:

It must be nominal (between 20 K and 19 K): it means that it must not vary along the test from point 0 to point 5. It is acceptable that during STEP 0 the SCS TSA is not tuned yet.

Reference Load temperature

The required thermal stability depends on the STEP considered. The CSL cooldown curve has been used to extract the required reference numbers (See APPENDIX 2)

N	T 4K STAGE	STABILITY	HOLD POOINT*	SLOW DOWN
STEP 0	30 K – 22 K	< 0.04 K/h	YES	NO
STEP 1	22 K	≤ 0.01 K/h	YES	NO
STEP 2	19 K – 17 K	< 0.025 K/h	NO	YES
STEP 3	17K – 13 K	< 0.025 K/h	NO	YES
STEP 4	5 K – 4 K	≤ 0.01 K/h	YES	NO

Table 4 for each step, the 4K stage absolute temperature together with the thermal stability are displayed. The two last columns display whether the step is to be considered or not and hold point and whether it is necessary or not to slow down the 4K stage cooldown (basing on data from CSL test campaign)

* Hold point means that the successful conclusion of this step (in terms of data recording and analysis) is mandatory in order to proceed ahead with the following step.

Sky signal temperature
No special pointing requirements are set: baseline pointing is required.

Phase switch tuning
Phase switches can also not be tuned during the STEP 0 , in the case it was useful to save time.

5.2.4 TIMELINE:

Here follows an attempt to calculate the Hyper Matrix Tuning timeline. For each point (quadruplet) two more seconds are considered, required to send TC and receive acknowledgment.
The net time, necessary to run the test, is displayed in the following table. Waiting time between steps is not considered.

STEP #	Vg tuning	Vd Tuning	Total time	Time (d,h,m)
STEP 0	86240	NO	86240	23h 57'20''
STEP 1	97500	10800	108300	1d 6h 5'
STEP 2	97500	10800	108300	1d 6h 5'
STEP 3	97500	10800	108300	1d 6h 5'
STEP 4	97500	10800	108300	1d 6h 5'

Table 5 time necessary for each step considering also time necessary for sending TC and receiving feedback.

The above timeline has been projected onto the CSL timeline, in order to understand whether it fits or not.

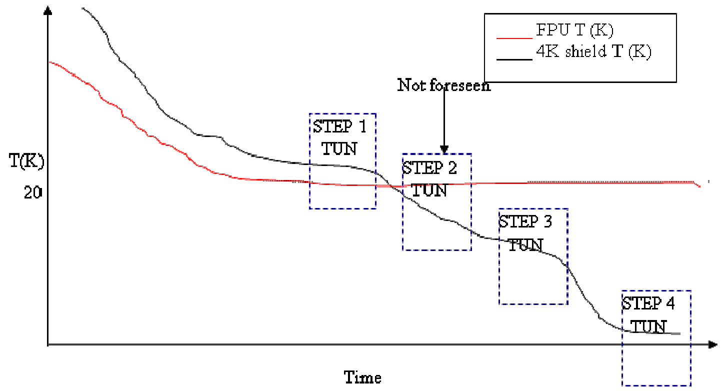


Figure 4 conceptual scheme of the MATRIX Tuning performed in CSL. FPU and 4K shield curves are the true ones.

If we base on the above CSL timeline, represented in the above graph and in the following table and figure, it seems that the region where 4K stage is above 17.5 K can be useful for the purpose.

Time (h)	4K T (K)	DT/h (K/h)
0.0	21.90	****
15.4	21.24	-0.043
69.7	19.48	-0.033
107.4	18.62	-0.023
150.2	17.96	-0.015
183.3	17.50	-0.014
235.3	14.00	-0.067
248.5	10.01	-0.302
260.3	5.02	-0.421

Table 6 CSL timeline (from left: hours, 4K stage temperature, cooldown slope in K/h)

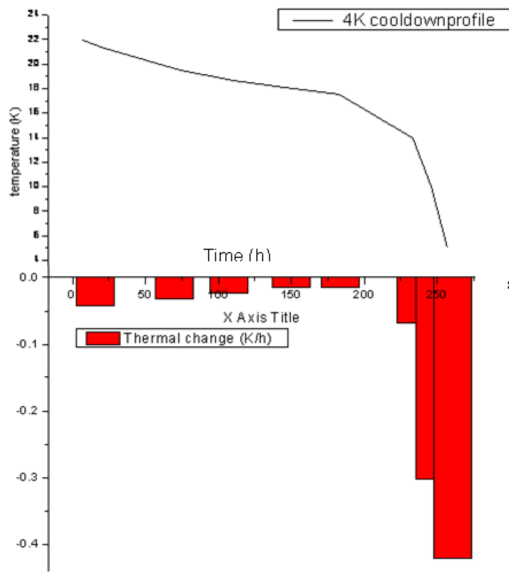


Figure 5 4K stage cooldown in CSL (top graph) against its slope in K/ h (bottom graph). X axis represents time in hours.

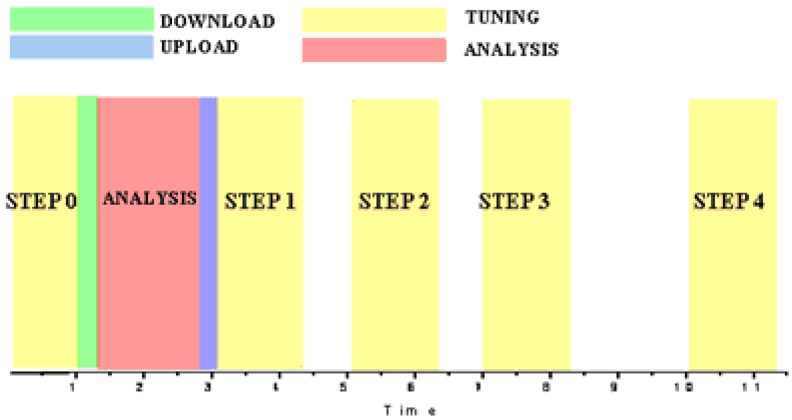


Figure 6 Test flow projected onto the timeline: waiting time is not defined and displayed blank.

5.3 Impact on HFI side

This strategy has mainly two consequences on the HFI

a) the time HFI is required to keep hold the 22K point

b) the HFI capability to slow the 4K shield cooldown using 1.6 K stage flowing Helium at weak rate (come out to be feasible during CSL test campaign)

Both them have to be deeper evaluated together with HFI team.

5.4 Impact on SCS side

This strategy appears to have not evident impact on SCS operations different respect to matrix tuning already performed in CSL.

6 APPENDIX

6.1 APPENDIX 1

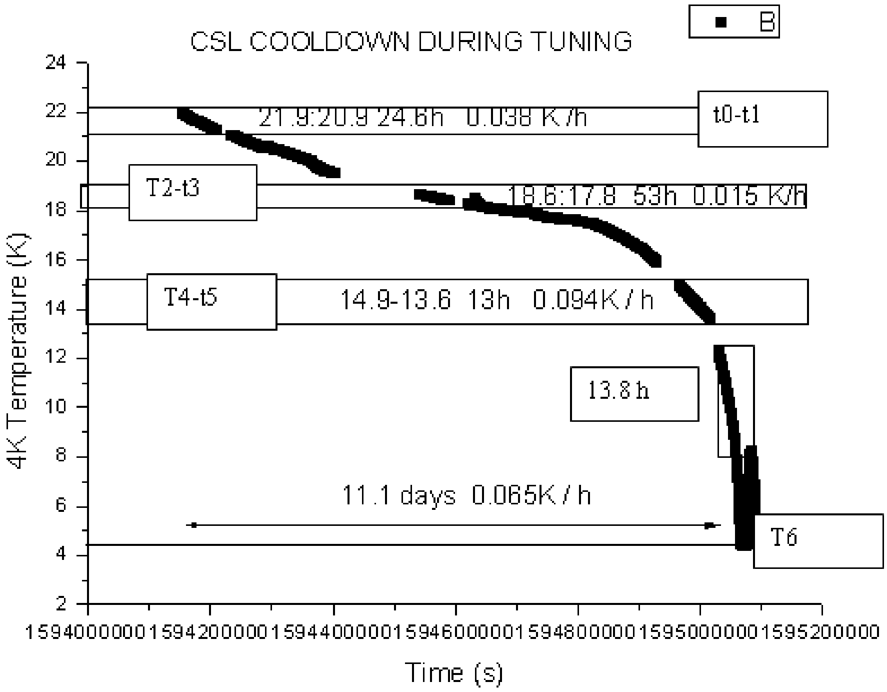
In the following table it is represented the mutual crosstalk between receivers when bias are changed over any of them. Analysis comes from data taken in CSL during matrix Tuning.
Values represent the ratio R= sigma Voltage (signal induced) / sigma voltage (when the channel is tuned) .
Blue and red cells corresponds to data not available or not representative for this analysis purpose due to the Tuning strategy followed.
Green filled cells are representative of a strong interference: the cutoff value chosen is 1/20, that is compatible with the average variation caused by one step of bias change.
The table in the bottom shows the possible grouping of not interfering channels coming out fronm this analysis.

	19	20	28	18	26	23	25	27	24	21	22
19		1.0E-01	1.5E-02	5.0E-02	3.0E-04	1.0E-02	3.5E-04				
20	3.3E-02		5.0E-03	1.7E-02	3.3E-04			1.3E-03	6.7E-04	1.7E-03	1.3E-03
28	2.5E-01	3.0E-01		2.5E-01	4.0E-03	5.0E-02	4.0E-03	2.0E-02	3.0E-03	5.0E-02	5.0E-02
18	5.0E-03	1.0E-02	2.0E-03		1.0E+00	1.0E-02	1.0E-03				
26	8.8E-02	1.9E-01	3.8E-02	8.8E-02		1.3E-01	7.5E-03				
23				3.3E-02	6.7E-04		3.3E-03	2.7E-03	1.3E-03	3.3E-03	2.7E-03
25	1.0E-01	1.3E-01	5.0E-02	7.5E-01	5.0E-02	8.8E+00					
27	1.4E-02	3.0E-02	6.0E-03	1.4E-02		2.0E-02	1.2E-03		2.0E-03	6.0E-02	6.0E-02
24	1.0E-01	1.3E-01	5.0E-02	7.5E-01	5.0E-02	8.8E+00		5.0E-01		1.3E+00	2.3E+00
21	2.5E-03	5.0E-03	1.0E-03			5.0E-03	5.0E-04	7.5E-03	7.5E-04		2.5E-02
22				5.0E-02	3.0E-04	1.0E-02	3.5E-04	1.5E-02	1.0E-03	5.0E-02	

GROUP1	24	26	28
GROUP2	25	27	
GROUP3	18	19	22
GROUP4	20	21	23

6.2 APPENDIX 2

4K-cooler stage cooldown during CSL test campaign. Matrix tuning was performed in the following ranges.
STEP 1 : t0-t1
STEP 2 : t2-t3
STEP 3 : t4-t5
STEP 4 : >t6
The Step duration and the cooldown average slope (in K/h) are also displayed on the plot.and in the table below.



	time	temp	sensit	duration (h)
t0	0	21.904		
t1	88540	20.9613	-0.0383	24.59
t2	386723	18.6189		
t3	578284	17.8143	-0.0151	53.21
t4	812476	14.8932		
t5	859340	13.659	-0.0948	13.02
t6		961797	0.0651	**11.13 days**

6.3 APPENDIX 3

In the framework of the above sequence we have considered the possibility to include drain voltage (Vd) modifications in the bias matrix. This is because similarly to the gate voltages we do not know precisely the real drain voltage value at the FEMs because of the effect produced by ground shifts and voltage drops on Vd.

Tests performed on the 30 GHz Flight Spare (LABEN-ALENIA SPACE, 2007-2008), showed that it is possible to improve noise and Isolation performances by including Vd in the bias matrix. Although just one spare RCA was tested it is expected that, including Vd in the tuning process could provide better bias points, especially for 44 GHz channels, that at present operated with a particularly low Vd; moreover, it must be added that, after pre-tuning, Vd will be changed only over a very restricted subset of Vg quadruplets.

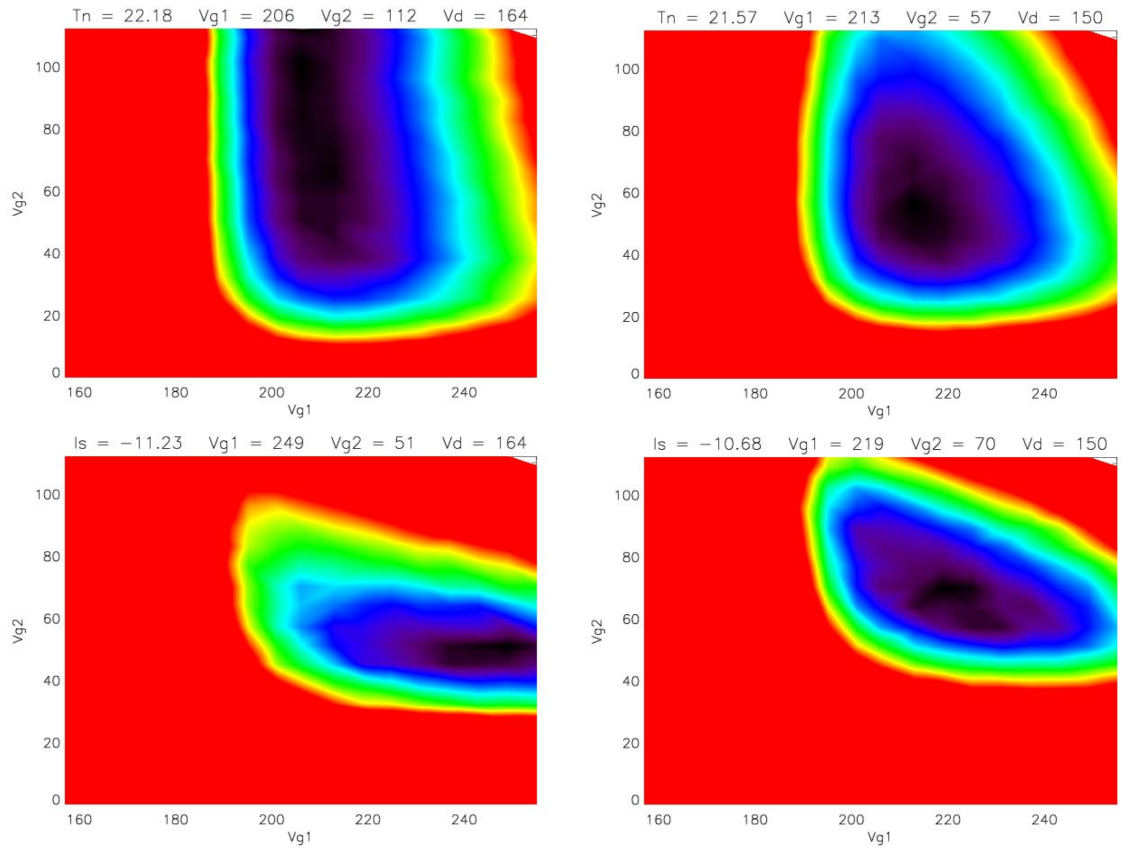
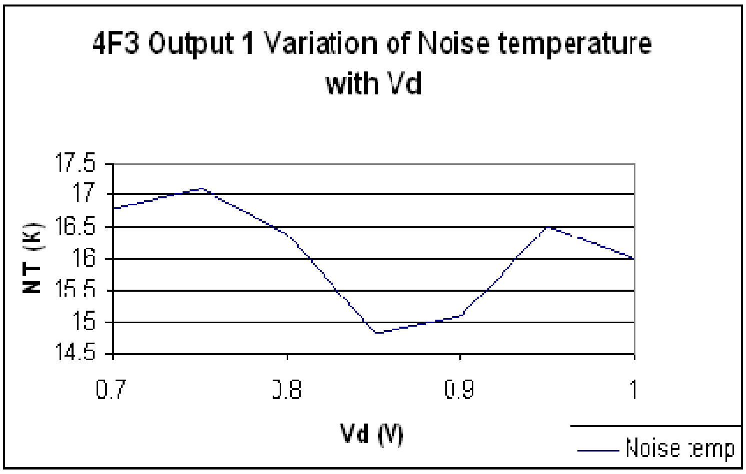


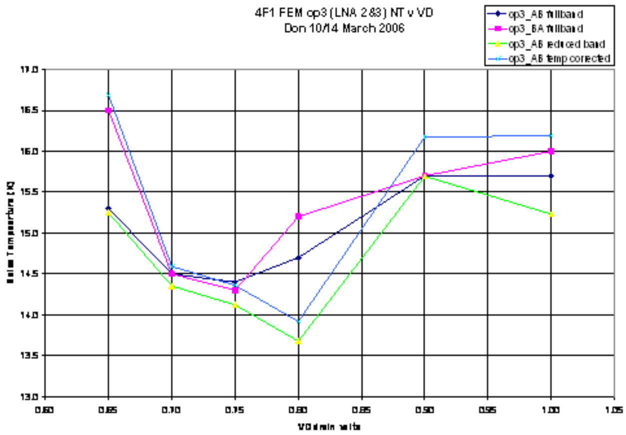
Figure 7 Vd change from nominal 164 DEC (left panel) to 150 DEC (right panel) during FS 30 GHz matrix tuning. Both Noise temperature (upper pictures) and Isolation (lower pictures) seem to improve , although slightly (respectively by 0.6 K and 0.55 dB), in the case here considered. Moreover, solutions appear to be more strong (consistency between noise temperature and Isolation) in the Vd tuned case (right panels)

Analysis at FEM level performed in JBO-Manchester shows how it is possible to optimize the Noise temperature, bandwidth and Gain by changing Vd.



Vd	NT (K)	Gain (dB)	Eff band (GHz)
0.7	16.8	28.9	6.91
0.75	17.1	29.5	7.06
0.8	16.4	30.1	7.03
0.85	14.8	30.7	7.05
0.9	15.1	31.2	6.95
0.95	16.5	31.5	6.94
1	16	31.9	6.92

Figure 8 Noise Temperature variation on RCA 26 when Vd is changed ; effect on Gain and bandwidth are also shown in the table on the right



Vd	NT (0) K	NT (1) K	Gain
0.65	15.3	16.6	32.6
0.7	14.3	14.5	33.1
0.75	14.1	14.4	33.3
0.8	13.7	15	33.4
0.9	15.6	16.2	33.7
1	15.5	16.1	33.8

Figure 9 Noise Temperature variation on RCA 25 when Vd is changed ; effect on Gain is also shown in the table on the right.