TITLE: ***'R-factor'* excess in *LFI-28***

DOC. TYPE: **TECHNICAL NOTE**

PROJECT REF.: **PL-LFI-PST-TN-102** **PAGE:** **1, 27**

ISSUE/REV.: **1.0** **DATE:** **February 2012**

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CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
Issue 1	Feb, 10th 2012	All	Draft issue of document	0.1
Issue 2	Feb, 20th 2012	All	First issue of document	1.0

SUMMARY

Introduction

It was several times observed that LFI28 channel shows very different R-factor values in the Main and Side arms. This note wants to investigate this feature trying to answer at least several of the many open questions regarding the origin of this behavior and its possible causes.

1. Description of the effect.

The effect observed on LFI 28 can be summarized as it follows. We get very different R factors (*R=Vsky/Vref*) on *Main* and *Side* arms despite of the similar *Noise Temperatures* characterizing the four outputs. In particular, the *Main* arm (M) shows higher *R-factors* respect to the *Side* arm (S). Typical values during the nominal flight operations are 0.96 $_{(+1/-0)}$ for the *Main* arm and 0,92 $_{(+1/-0)}$ for the *Side* arm. This 0.04 difference in *R-factor* was unexpected, due to the fact that it would imply very different noise temperatures between M and S channels or, alternatively, different input temperatures at the level of SKY signal (in principle unique) and REF signal (provided by two Reference Loads in principle identical) . The complete equations describing the problem were well described in [REF-1]. For our purpose we will use only those equations useful to describe the various aspects investigated.

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To fully comprehend the implications of this feature, we can analyze the typical outputs of LFI28, calculating the Noise Temperature from the SKY – REF signal unbalance (following the method adopted during the CPV Pre-Tuning [**Errore. L'origine riferimento non è stata trovata.**]). From OD 791 we get for LFI28 the values reported in the Table 1. The *Noise Temperature* was calculated supposing T_{SKY}= 2.73K (2.073K in Antenna Temperature), and measuring , through the 4K Cernox sensor, T_{REF}=4.34K (3.66K Antenna Temperature) . The *Noise Temperature* (*Tn*)is calculated through a modification of the pure *Y-factor* method , with $Y^*=<V_{SKY>}/<V_{REF}>$ and $Tn = \frac{(T_{SKY}-Y^{*}\cdot T_{REF})}{(Y*-1)}$

CH#	SKY	REF	R	T-NOISE	Cal. Const. (K (*RJ*)/V)
28M00	1.128	1.157	0,975	59,89	54,72
28M01	1.429	1.482	0,964	40,68	29,94
28S10	1.023	1.105	0,926	17,36	19,35
28S11	0.893	0.973	0,918	15,24	19,83

Table 1 LFI-28 : R-factor, Noise Temperature and Calibration Constants calculated for each output voltage (SKY and REF voltages are indicated in the second and in the third column)

Table 1 shows, despite of the approximations intrinsic with the method, the very different noise temperature and Calibration Constants characterizing M and S diodes. Independent measurements performed during CPV [**Errore. L'origine riferimento non è stata trovata.**] and during the nominal mission [REF-2] demonstrate that, while results found for S diodes are similar to the true results, the same is not for M diodes.

2. Origin and stability of the effect

We went back in time through CPV campaign down to the beginning of CSL ground test campaign (2008,REF-3) to track the R-factor, in order to verify its possible dependence on particular setup. Moreover we also verified the possibility that any other non-ideal behaviors could have triggered or caused it.

		R0D0	R0D1	R1D0	R1D1
T1	I-V Curves (CPV) REF@ 4K	0,973±0.003	0,964±0.005	0,928±0.01	0,922±0.01
T2	I-V Curves (CSL) REF @ 20K	0,559±0.003	0,569±0.003	0,546±0.003	0,532±0.003
T3	Ref. Test CPV(REF≈4.5K, SKY≈2.7K)	0,974±0.008	0,961±0.005	0,926±0.008	0,916±0.006
T4	Ref. Test CSL(REF≈SKY≈4.5K)	1,056	1,032	1,011	0,986
T5	CRYO-02 CSL (XXX_0154) REF ≈ 22K	0,567±0.005	0,567±0.001	0,54±0.02	0,529±0.002
T6	CRYO-02 CSL(REF≈SKY≈4.5K)	1,051±0.012	1,036±0.006	1,003±0.009	0,996±0.009
T7	ACA MATRIX TUN CSL STEP1 REF ≈ 21.3K	0,597	0,599	0,573	0,543
T8	LFI switch ON CSL				
T9	DAE Tuning				
T10	LFI24 oscillation (XXX_0182)	1,049	1,038	0,996	1,001
T11	LFI28 Soft switch (TUN_080)	0,726	0,723	0,694	0,687
T12	LFI23 Phase switch (XXX_0155)	0,597	0,599	0,573	0,543

***Table 2 R-factors* calculated for several tests from CSL and CPV campaigns demonstrate that the R-excess has been existing at least since the beginning of the LFI CSL campaign and remained about constant.**

The results obtained from the tests summarized in the Table 2 rule out most of the possible dependences on the instrumental setup. For each of the following items it can be stated what it follows.

R is independent on the LNAs bias chosen:

I-V curves measured during CSL and CPV tests confirm the R-factor asymmetry between M and S for all the *LNA*-bias pairs exercised.

***R is independent on the PH/SW status*:**

CRYO02 Test performed in CSL (T4,T5, T6 in Table 2) and in CPV (part 2 of the Reference Test, T3 in Table 2) confirm that the large R measured on *M-arm* do not depend on the phase switch status (for each diode, the spread of R’s through the phase switch setup applied is traced by the rms shown aside of each R value in the corresponding rows).

R could just weakly depend on the input signal

The R excess is for example present both in test performed with the Reference Load at T > 20K and when its temperature was nominal around 4.5K (compare T1 vs T2; T4 vs T5 and T7). However this point will be investigated deeper in the next paragraphs, to look for a weak dependence on the temperature of the input loads (either REF or SKY).

R asymmetry has been existing at least since the beginning of CSL test campaign

The numerous tests performed and reported in the table show that the asymmetry does not varies with on the test setup and remained the same at least from the LFI switch on in CSL .

R is independent on the insurgence of any anomaly on LFI24

this channel was discovered for the first time in CSL to require a particular procedure when switched on: this is mandatory in order to avoid oscillation (**Errore. L'origine riferimento non è stata trovata.**). R was checked before and after the first appearance of the problem and while the oscillation was exhibiting: in all the cases the asymmetry is present **.**

R is independent on the insurgence of any anomaly on LFI28

this channel was found during ground tests in LABEN (REF-5) to require a well-defined sequential switch on of the gate and drain stages. No evidence of any relations with it is found (T11).

R is independent on the insurgence of any anomaly on LFI23

In some configurations of the P/S , LFI23 is able to induce oscillations on other channels also not sharing the same power group(REF-2). However, T12 shows that the R asymmetry does not depend on this.

As a first conclusion we can summarize that: (i) R asymmetry was already present at the same level at least since the CSL ground test campaign and (ii) we have no evidence of relations with the LNAs Bias setup, with the PH/S status, with the DAE setup, with most of the known non ideal behaviors of LFI radiometers.

3. Analysis of the effect

High R values can be analytically obtained in two different ways:

(i) lowering the input from Reference Load
(ii) increasing the input from Sky signal

We investigate both the options, going into the details of each and excluding everything is not reliable basing on measures.

3.1 Low signal from the Reference Load.

This effect can be generated in two ways:

a) Supposing Ohmic losses at the level of:

   i. Reference Horn: caused for example from aging effects degrading the metal surface roughness (the waveguide and the RH are not gold plated inside)

   ii. Hybrid input from the reference Horn arm.

b) supposing a mismatching between the Reference Horn and the Reference Load just in the M-arm, due to:

   iii. bad design,

   iv. cracks in the Load

   v. damages /obstructions in the Horn

   vi. damages in the Hybrid (reference arm)

The point a) is ruled out in the both options (i) and (ii): in fact any losses occurring before the first stage of amplification would cause a power excess proportional to the physical temperature of the cold stage(20K) and to the Insertion Loss.

The point b) is in principle possible, but requires deeper analysis.

<u>The first question to be answered is:</u> which is the input load explaining this signal lack?

We advantage of the four steps of the Hyper Matrix Tuning performed in CPV to calculate it. The Reference Load temperature was changed as reported in Table 3.

	Step1	Step2	Step3	Step4
T phys	19,162	18,288	16,552	4,426
T ant	18,45	17,58	15,84	3,75

Table 3 Physical and Antenna Temperature at 30 GHz during the 4 steps of the HYM Tuning in CPV

As done in the case of results presented in Table 1, we calculate $Y^{*}=V_{SKY}/V_{REF}$ along the four steps to calculate the noise temperature (Table 4) ; hence we calculated *R-factor* (Table 5). Results show two things: the R asymmetry is present along all the four steps; the ratio $R_R = \frac{\langle R_M \rangle}{\langle R_S \rangle} = \frac{\langle V_{SKY_M} \rangle}{\langle V_{REF_M} \rangle} \cdot \frac{\langle V_{REF_S} \rangle}{\langle V_{SKY_S} \rangle}$ of the average R calculate on M and S is quite constant along the four steps; the Noise Temperature looks only weakly affected by the R asymmetry in the first three steps (performed in conditions of similar input load) while it is strongly affected in the fourth step.

CH#	*STEP1*	*STEP2*	*STEP3*	*STEP4*
LFI2800	20,29	20,27	20,25	51,53
LFI2801	20,50	20,44	20,34	39,49
LFI2810	18,55	18,44	18,24	17,57
LFI2811	17,35	17,24	17,05	16,30

Table 4 Noise Temperatures calculated from Y*-factor

CH#	*STEP1*	*STEP2*	*STEP3*	*STEP4*
LFI2800	0,577	0,590	0,619	0,970
LFI2801	0,580	0,592	0,619	0,961
LFI2810	0,557	0,570	0,596	0,922
LFI2811	0,543	0,555	0,581	0,917
$\langle R_M \rangle / \langle R_S \rangle$	1,051	1,050	1,051	1,050

Table 5 R-factors for each diode and temperature step of the HYM-Tuning in CPV; The last row shows R_R calculated for each step.

At first level we can suppose that the Noise Temperature measured in steps from 1 to 3 is close to the true value and we resolve EQ (1) to get the unknown observed load T_{ANTX} reported in Table 6

EQ (1) $T_{ANTX} = (Y-1) \cdot T_{NOISE1,2,3} + Y \cdot T_{SKY}$

CH#	T_{ANTX}
LFI28-00	2,744K
LFI28-01	2,941K

Table 6

To calculate the corresponding Return Loss (RL) accounting for this lack in power we must consider that any mismatching between the Reference Horn (at 20K) and the facing Load (at 4,5K) cause also a reflection of the thermal power from the Reference Horn (at 20K) in the direction of the cold amplifiers. This power (T_{FEM}) is weighted by the Insertion Loss (*IL*) of the Reference Horn arm convolved by the Return Loss. It means to solve the equation :

EQ (2) $RL_X = (T_{ANTX} - T_{ANT\text{-}4K}) / (IL * T_{FEM} - T_{ANT\text{-}4K})$

The solution of this equation is however unacceptable: actually, when we re-calculate the Noise Temperature of the first three steps basing on the RLX found, we get results in contradiction with the hypothesis of a unique *Noise Temperature* along the four steps. (Table 7):

	Step1	Step2	Step3	Step4
TN	13,070	13,064	13,052	19,430

Table 7

Hence we must solve a system an over determined system of four equations (one for each step) in two unknowns: *Noise Temperature* (T_{NX}) and *Return Loss* (RL_X)

EQ (3)
$$
\begin{cases}
RL_X = [(Y-1)*T_{NX}+Y*T_{SKY} - T_{ANT\text{-}step1}] / (IL*T_{FEM} - T_{ANT\text{-}step1}) \\
RL_X = [(Y-1)*T_{NX}+Y*T_{SKY} - T_{ANT\text{-}step2}] / (IL*T_{FEM} - T_{ANT\text{-}step2}) \\
RL_X = [(Y-1)*T_{NX}+Y*T_{SKY} - T_{ANT\text{-}step3}] / (IL*T_{FEM} - T_{ANT\text{-}step3}) \\
RL_X = [(Y-1)*T_{NX}+Y*T_{SKY} - T_{ANT\text{-}step4}] / (IL*T_{FEM} - T_{ANT\text{-}step4})
\end{cases}
$$

If we look for an approximate solution in T_{NX} we find that the equation is satisfied within a precision of 0,3K in T_{NX} both on *LFI28-00* and on *LFI28-01* . Results (to be compared to those in Table 4) are reported in Table 8.

CH#	RL (dB)	RL (%)	IL (dB)	STEP1(K)	STEP2(K)	STEP3(K)	STEP4(K)
LFI2800	-3,89	-40,8	0.15	12,28	12,24	12,16	11,80
LFI2801	-4,43	-36.0	0,15	10,94	10,92	10,88	11,10

Table 8 Results from Y*-factor method applied to HYM Tuning, using as input parameters results from EQ (3). IL is the Insertion Loss used for the Reference Horn arm, basing on results from *Errore. L'origine riferimento non è stata trovata.*

	Step1	Step2	Step3	Step4
T phys	19,162	18,288	16,552	4,426
T ant	11,610	11,092	10,065	2,484

Table 9 Observed Reference Load antenna temperature when the Return Loss model is applied.

In the case that we apply the RL found to calculate the Noise Temperature from pure Y-factor method advantaging of the 4K Reference Load cool-down during CPV , we get results comparable with those obtained from the Hybrid Y*-factor method. Results are the same considering a linear fit over the whole data set (4 steps) and over just the 3rd and 4th steps to minimize possible non-linear effects effects)

	$T_{ANT\text{-}}$ Model		$T_{ANT\text{-}}$ without corrections	
CH#	*STEP 1,2,3,4*	*STEP 3,4*	*STEP 1,2,3,4*	*STEP 3,4*
LFI2800	10,54	10,95	*18,95*	*17,70*
LFI2801	11,44	11,89	20,20	18,40

Table 10 Noise temperatures calculated from Y-factor method

From results in Table 8, we notice that: (i) the noise temperature obtained are lower than in all previous calculated at CSL and CPV level, also basing on independent methods (ii) the solution forLFI28-00 and

LFI28-01 is not unique in the RL: they differ by about 4% in terms of reflected radiation. In principle this would be nonsense because of the uniqueness of the 4K Reference Load; however, due to the small difference and to the approximation of the calculation it could be considered as acceptable.

From results in Table 10 and from comparison to Table 8 we notice that:

(i) in the case of pure Y factor calculation we get reliable results in both cases (RL accounted for or not) : this is a first hint of that R-asymmetry does not affects the relative variation of the 4K reference load input signal, providing the Gain.

(ii) (ii) The RL model is able to match results obtained from the Hybrid Y*-factor method and from pure Y-factor.

It is also worth noting the amount of radiation reflected obtained resolving the model. Actually about 40 percent of the incoming radiation would be reflected. This number is un-realistic if we consider the 4K Reference Load properties. It could not be explained just basing on a crack or on a misalignment . In fact, performance measurements on the 4KRL FM units reported in **Errore. L'origine riferimento non è stata trovata.** demonstrate that the RL is always better than -23 dB also when considering lateral displacements up to 2 mm and axial displacements up to 1,5 mm (meaning the Load in contact with the Horn).

Analysis performed on test loads, cracked following cryogenic stress-tests, demonstrated also that the change in the return loss of the damaged Load is marginal.

Possible explanations could instead be: (i) obstructions / anomalies (for instance caused by un-perfect gold plating , see **Errore. L'origine riferimento non è stata trovata.**) in the Reference Load arm of the hybrid; a very important failure in the Reference Horn causing a break in the wave transmission.

3.1.1 hypothesis verification

Results from the analysis rule out the hypothesis of large mismatching in the Reference Load.

The smoking gun for this model is represented by the calibration constant: in fact, in the case that the loss occurs before amplification, we should get very different calibration constants when calculated from SKY or REF signal changes. This analysis could also explain the why the pure Y-factor method suffers only weakly the *R –factor* asymmetry.

We can advantage of several tests performed in CSL and in CPV, when the sky signal (Sky Load *Helium refilling* in CSL, *Dipole modulation* during the First Light Survey) or the Reference Load signal (*LNAs Tuning* in CSL and CPV, *HFI Heat lift tests* in CSL, *4K Cooler failure* in CPV) were varied over different ranges. As a double-check we calculated the same quantities also for LFI 27, not showing any evident asymmetries in R.

	Cal Constant (K/V)				% difference w.r.t FLS			
rca27	R0D0	R0D1	R1D0	R1D1	R0D0	R0D1	R1D0	R1D1
4K FAILURE (CPV)	14,49	13,58	15,48	17,31	11,47	12,37	12,15	7,36
STEP REF @7k (CSL)	13,86	13,06	14,67	16,86	6,63	8,09	6,27	4,56
STEP REF 1,3k (CSL)	13,18	12,21	13,87	16,24	1,41	1,09	0,46	0,69
SKY refill 70uK (CSL)	12,67	11,67	13,45	15,27	-2,53	-3,41	-2,57	-5,30
FLS (post CPV)	13,00	12,08	13,80	16,12	0,00	0,00	0,00	0,00
RCA28								
4K failure (CPV)	17,22	13,66	17,95	19,32	0,29	1,71	-0,61	-0,87
STEP Ref @7k (CSL)	16,95	13,35	18,05	19,47	-1,28	-0,58	-0,06	-0,09
STEP Ref 1,3k (CSL)	15,91	12,57	16,90	18,34	-7,36	-6,39	-6,45	-5,91
sky refill 70uK (CSL)	16,54	12,99	17,33	18,90	-3,67	-3,28	-4,04	-3,03
FLS (post CPV)	17,17	13,43	18,06	19,49	0,00	0,00	0,00	0,00

Table 11 calibration constant calculated for LFI-27 and LFI-28 during several tests. Values are also compared for each diode to those measured during the **First Light Survey** ***(reported in the last row).***

		STDEV normalized to FLS			
		R0D0	R0D1	R1D0	R1D1
RCA27	REF STEPS	5,03	5,69	5,84	3,35
	SKY STEPS	1,79	2,41	1,82	3,75
	SKY&REF	5,62	6,43	5,93	4,82
RCA28	REF STEPS	4,04	4,18	3,54	3,16
	SKY STEPS	2,59	2,32	2,86	2,14
	SKY&REF	3,18	3,17	2,89	2,51

Table 12 Calibration constant standard deviation normalized to the value measured during the FLS. Results are grouped per channels and per input loads changes: in REF, in SKY, and together in REF and SKY.

Results presented in Table 11 and in Table 12 show, within a reasonable error margin (moreover larger for LFI 27), that calibration constants calculated using SKY signal or REF signal variations are consistent. **This result rules out the possibility of a signal lack in the REF signal occurring before the cold LNA amplification**: in fact , it would produce a discrepancy in the Calibration constants comparable with the percentage of radiation reflected (hence calibration constants much larger than measured) .

3.2 Insertion Loss at SKY arm level.

The alternative possibility to get large R’s is based on a signal excess from the sky arm. It could be modeled through an insertion loss occurring in the first hybrid or in the OMT, before signal amplification. In fact , any loss following the amplification stage would be weighted by the LNAs gain (reducing by a factor about

1000) ; any loss in the reference horn would be seen also in the S channel (although it could be in principle compensated by an equal loss in the *Side* Reference arm) .

The case of some extra losses in the line OMT-Hybrid would cause simultaneously a lack in sky signal and an increase in the Ohmic emission proportional to the temperature of the Front End (hold around 20K)

As in the case before, we implemented the model accounting also for this term. It correspond to add equation EQ (4) to the equations EQ (3).

EQ (4) $T_{SKY} = 2{,}73K * (1- ILX) + ILX * 20K$

This implies to solve the full system independently for LFI28-00 and for LFI28-01 keeping as principal unknowns ***ILX*** and $\boldsymbol{T_{NX}}$ and allowing $\boldsymbol{RL_X}$ to run over a reduced set of values (namely $|\boldsymbol{RL_X}| > 20$ dB) in order to minimize the effect of Horn – Load mismatching.

Starting again from the CPV Hyper Matrix Tuning data we found two independent solutions for the two coupled diodes:

CH#	*RL_{REF} (dB)*	*IL_{SKY} (dB)*	*IL_{SKY} %*	*IL_{SKY} (K)*	*STEP1(K)*	*STEP2(K)*	*STEP3(K)*	*STEP4(K)*
LFI2800	-23,6	0.215	4,8	0,96	18,9	18,8	18,8	19,7
LFI2801	-27,4	0,19	4,3	0,85	19,4	19,3	19,2	17,6

***Table 13 Results from the IL model applied to HYM Tuning. IL_{SKY} is the Insertion Loss input value used for the SKY arm, basing on results from EQ (4) and EQ (3).* IL_{SKY} (K) is the physical temperature excess observed .**

What we notice is that we have not unique solutions in the two diodes for what concern the Insertion Loss of the sky arm and the Return Loss of the Reference Load; moreover we pay a difference in noise temperature between the first three steps and the fourth of about 1,5K . However, considering the approximation of the method, these discrepancies seem acceptable .

3.2.1 hypothesis verification:

The model preserve the calibration constants: less then 5% of the sky signal goes, introducing an error of the same order in the calibration constant estimation.

What does matter is the differential loss between SKY and REF arms in Main and Side radiometers: the amount of it is large (just basing on specifications) but absolutely not unbelievable . We have also to remind that the Front End Modules at 30 GHz have undergone a gold re-plating machining due to exfoliation observed in in the hybrids. degradation could explain the Loss increase.

The thermodynamic excess in the sky signal (about 1K) is moreover consistent with results from ground tests, when the 4K reference load temperature was moved up and down. In fact , as displayed in Figure 1, the 4K reference Load temperature must be increased by about 1K (starting from 4,5K) to make the REF signal cross the SKY signal, although the nominal temperature of the two loads was about the same (CSL, test XXX_0229). Nevertheless we must observe that in two coupled diodes **the REF signal cross the SKY signal at two different times**, when the common reference load was changed in temperature by two hundred mK (*temperature gap*).

Moreover, during the same test, two LNAs bias setup were applied, mostly different in the LNAs gain. The two setup show **different *temperature gaps*** in the two coupled diodes. This could be caused by

(i) different Gain ratios of the LNAs in the two coupled legs
(ii) small asymmetries at the level of PH/SW.

The two possible causes will be better investigated in the next section.

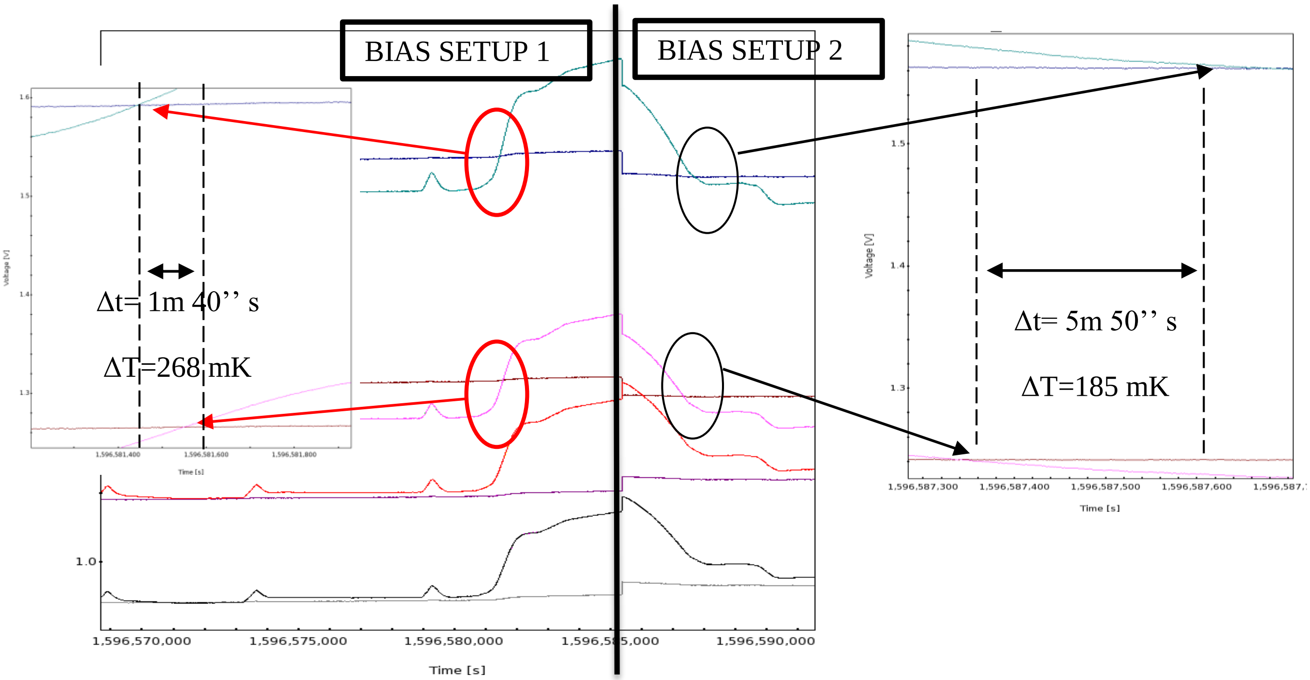

Figure 1 4K reference load heat lift test in CSL: the 4K stage temperature was increased from about 4,5 K up to about 7 K ,than decreased again for two different bias

3.3 Differential Losses introduced by PH/SW

A non-negligible contribution to large R's and to differential behavior in the two coupled diodes could come from some loss affecting the signal at the level of the Phase switch. In fact we just make an approximations when considering the phase switches as lossless devices. Phase switches can introduce a net loss in the signals coming out from the first hybrid in two different ways:

- reducing the insertion gain due to Ohmic losses in the device
- back reflecting the incoming signal due to non-null mismatching with hybrid.

The combination of the two above effects produces a reduction in the forwarded signal (input signal plus cold LNAs noise temperature). This is why from now on we will refer to as *signal loss* instead of insertion loss.

By design , measured under the nominal bias conditions at RF bench (**Errore. L'origine riferimento non è stata trovata.**), the insertion loss would be less than 0,1 dB, and the Return Loss less than TBC dB.

We do not care about the different contribution from these two non-ideal effects to emission: the emission of extra signal at the Front End Temperature (20K) follows the LNA amplification, hence it is marginal. We do care here about the signal loss and about the possible physical process causing asymmetries in sky and ref signal.

Firstly, we checked that it is correct to assume that the phase switches can cause a non-negligible signal loss, depending on the biasing and on the status of polarization. The Phase Switch Tuning Test performed in CPV can answer this question. In fact it was executed keeping on only one of the two coupled amplifiers per time: the two signals exiting the second hybrid should be in principle equal. The aim of phase switch Tuning is to minimize the differences in the even and odd signals detected by the same BEM diode: however, in doing that, we introduce some attenuation in the signals. The amount of this attenuation must be evaluated w.r.t the incoming signal .

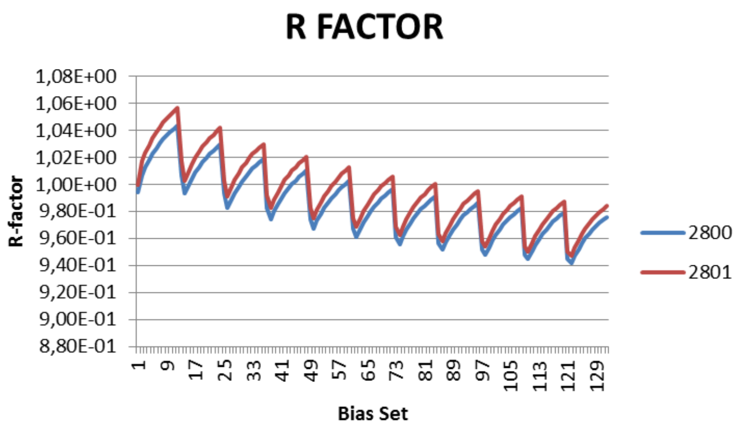

Figure 2

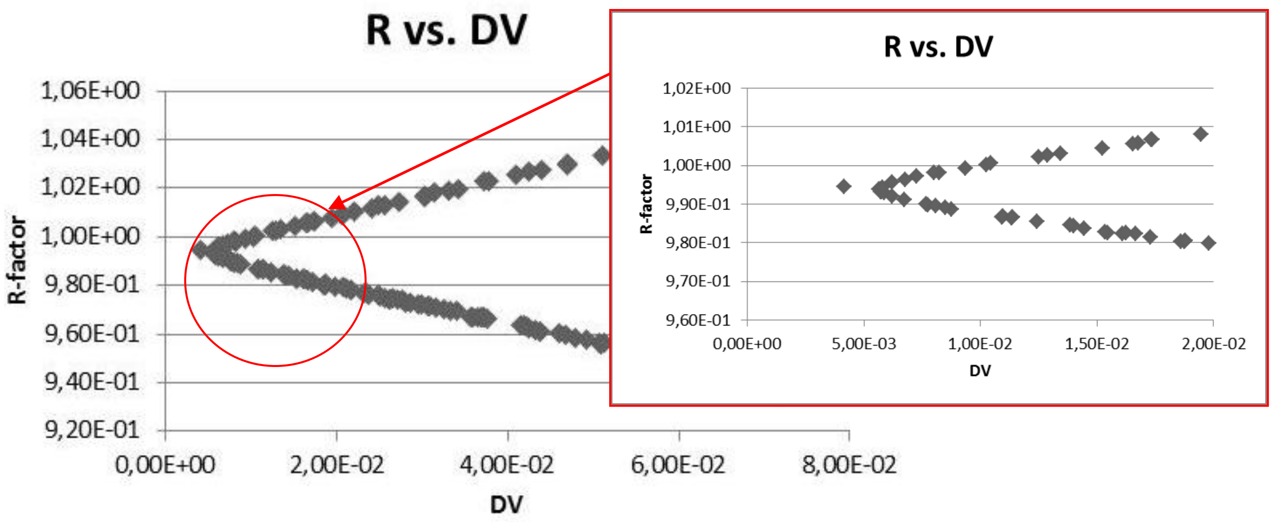

Figure 3

From Figure 2and Figure 3 we infer that:

(i) R factor varies with the (I1,I2) bias setup chosen.

(ii) The smallest DV does not automatically corresponds to *R-factor* closer to unity; this is a consequence of the insertion gain varying with bias setup.

We evaluated the expected signal loss for odd and even samples, normalizing to the maximum signal measured, : in fact, phase switches can-not amplify signal, only one LNA is on per time (hence the amplifiers Noise temperature is the same for odd and even states), and the input load is the same for both the PH/SW states. Hence any deviance from the maximum signal must be addressed to attenuations in the PH/SW circuit . Results, reported in Table 14, show that just playing with the phase switch bias it is possible to obtain percent changes in the forwarded voltage up to about 14 percent of the maximum voltage output. However, this is not the case of the bias default selected for LFI28: in fact, the loss measured in nominal bias conditions is within the range [-0.4% - 4%], depending on the channel and on the PH/SW activated in switching modality. As we can see from the Δ-SEL columns, different losses are generally introduced for even and odd samples (modulated at 4KHz): this effect is generally symmetric for the two coupled diodes V1 and V2.

		M1 ON		**M2 ON**		**S1 ON**		**S2 ON**	
		Δ MAX %	**Δ SEL %**	**Δ MAX %**	**Δ SEL %**	**Δ MAX %**	**Δ SEL %**	**Δ MAX %**	**Δ SEL %**
V1	even	3,69	-1,64	3,18	-1,55	2,90	-0,39	3,13	-1,41
	odd	6,75	-3,48	8,90	-2,17	7,54	-2,19	11,80	-2,73
V2	even	7,15	-3,83	9,80	-4,01	8,10	-2,35	13,31	-3,11
	odd	3,88	-2,30	3,33	-2,15	3,14	-0,42	3,66	-1,70

Table 14 Phase switch Tuning: loss calculated for even and odd samples w.r.t the maximum transmitted power : for each BEM diode they are displayed: Δ MAX, that is the peak to peak voltage excursion normalized to the maximum forwarded voltage; Δ DEL, that is the insertion loss suffered by the selected (I1,I2) bias configuration, normalize ad before to the maximum forwarded voltage.

3.3.1 hypothesis verification:

Loss at phase switch level can explain relevant R excess in each of the Main arm diodes, and asymmetries in R and in the differential signal among the two coupled Main arm diodes.

We tried to estimate the possible R increase due to anomalies at the phase switch level. Non idealities can be itemized as it follows:

→ Loss in one (or in both) state of the phase active 4KHz system

→ Loss in the still phase switch (that is the phase switch not commanded at 4KHz)

To guess a result , we based on the formulation reported in REF-9 (EQ2 and EQ4) , describing the output signal in function of various input parameters.

In this section we concentrate on the variation of the following input parameters:

→ ε_{A1}=1-A_1= insertion Loss of the active phase switch when polarized 0 ($\vartheta1=0$)

→ ε_{A2}=1-A_2= insertion Loss of the active phase switch when polarized 1 ($\vartheta1=\pi$)

→ ε_{AC}= 1-A_c= insertion Loss of the still phase switch when polarized 0 or 1 ($\vartheta1=0 ,\pi$)

→ $\varepsilon_{\vartheta1}$= phase error committed on $\vartheta1$

→ $\varepsilon_{\vartheta2}$= phase error committed on $\vartheta2$

EQ (5)

$$Sj,1 = e^{i\varphi B1} \cdot gB1 \cdot \left\{ nB1 + {}^{1}\!/_{\sqrt{2}} \cdot \left[\sqrt{Ac} \cdot e^{i\varphi F1} \cdot gF1 \cdot \left(nF1 + \frac{x+y}{\sqrt{2}} \right) + \sqrt{Aj} \cdot e^{i(\vartheta j + \varphi F2)} \cdot gF2 \cdot \left(e^{i\vartheta_{ij}} \cdot nF2 + \frac{x-y}{\sqrt{2}} \right) \right] \right\}$$

$$Sj,2 = e^{i\varphi B2} \cdot gB2 \cdot \left\{ nB2 + {}^{1}\!/_{\sqrt{2}} \cdot \left[\sqrt{Ac} \cdot e^{i\varphi F1} \cdot gF1 \cdot \left(nF1 + \frac{x+y}{\sqrt{2}} \right) - \sqrt{Aj} \cdot e^{i(\vartheta j + \varphi F2)} \cdot gF2 \cdot \left(e^{i\vartheta_{ij}} \cdot nF2 + \frac{x-y}{\sqrt{2}} \right) \right] \right\}$$

where j=1,2 are the two states of the phase switch.

EQ (5) is was slightly modified w.r.t the original one in REF-9 , in order to make it account for losses in the still phase switch (the $A_c=1-\varepsilon_{AC}$ term) and to impose that Noise contributions from Front End LNAs (*nF1* and *nF2*) always sum to the input signal (due to that they are uncorrelated signals); to obtain this, we introduced a phase term *EXP(i*ϑ_{ij})* multiplying *nF2*, with $\vartheta_{ij} = \vartheta1$ for i=j and equal $\vartheta_{ij} = \vartheta2$ for i≠j. *i* and *j* are the index of the voltage terms S_{ij} , where *i*=1,2 represents the voltage diode and *j* the status of the active phase switch .

Results are reported in Table 15. All parameters have been only slightly modified, to consider realistic non-ideal behaviors.

	r1	r2	d1	d2	dr1	dr2	dd1%	dd2%	r1-r2%	d1-d2%
Nominal	0,9276	0,9276	0,013759	0,013759	0,000	0,000	0,000	0,000	0,000	0,000
ε_1 =+5%	0,9365	0,9199	0,011955	0,015213	0,958	-0,826	-13,107	10,575	1,784	-23,68
ε_2 =+5%	0,9199	0,9365	0,015214	0,011955	0,826	0,958	10,575	-13,107	-1,784	23,68
ε_c =+10%	0,9252	0,9252	0,013759	0,013758	0,258	-0,258	0,000	0,000	0,000	0,000
ε_1 =+5%; ε_c =+10%	0,9344	0,9173	0,011956	0,015213	0,730	-1,111	-13,107	10,575	1,841	-23,68
$\varepsilon_{\vartheta 1}$ =+1°	0,9276	0,9275	0,013748	0,013767	0,006	-0,006	-0,078	0,064	0,011	-0,001
$\varepsilon_{\vartheta 2}$ =+1°	0,9275	0,9276	0,013768	0,013748	0,006	0,005	0,064	-0,078	-0,011	0,001
$\varepsilon_{\vartheta 1}$ =-1°	0,9275	0,9276	0,013768	0,013748	0,006	0,005	0,064	-0,078	-0,011	0,001
$\varepsilon_{\vartheta 2}$ =-1°	0,9276	0,9275	0,013748	0,013767	0,006	-0,006	-0,078	0,064	0,011	-0,001

Table 15 changes in R-factor and in the difference between even and odd samples produced by small insertion loss terms (ε_i) and by slight unbalance in the phases of the active phase switch ($\varepsilon_{\vartheta i}$). From left to right they are reported for the two coupled BEM diodes (i=1, i=2): R-factors (r_j) ; difference odd-even samples (di); percent variation of the R-factors normalized to the Nominal balanced condition (dr_i);); percent variation of the difference odd-even samples normalized to the Nominal balanced condition (dd_i); asymmetry introduced in the R-factor normalized to the nominal R (r1-r2);); asymmetry (d1-d2) introduced in the difference odd-even samples normalized to the nominal difference d_j (in the nominal condition d1 = d2) ;

From Table 15 we can extrapolate that the following non-ideal behaviors are feasible in different ways:

±1% change in R factor:

- adding 5% loss in the active phase switch.
- adding 30% loss in the still phase switch.
- mixing in different proportions the two above losses.

±10% change in signal difference (odd-even):

- adding 5% loss in the active phase switch

±2% asymmetry in R factors (between the two coupled diodes) :

- adding 6% loss in the active phase switch. The asymmetry has opposite effects, (meaning that (r1-r2)/r_N is positive or negative) depending on the status of the phase switch suffering the loss.

±4 % asymmetry in signal difference (odd-even, between the two coupled diodes) :

- adding 1% loss in the active phase switch. As for the R-factors, also this asymmetry has opposite effects, , (meaning that $(d1-d2)/d_N$ is positive or negative) depending on the status of the phase switch suffering the loss.

Losses at the level of the still phase switch are not able to produce any asymmetry in either R and signal difference.

Only marginal effects are introduced introducing ±1 degree phase error in the active phase switch.

3.4 Changes caused by other asymmetries in the coupled ACAs

We examine in this section other contributions given, caused by the asymmetries in devices other than phase switches belonging to coupled Amplifier Chain Assemblies (ACAs). Results are reported in Table 16. The effects considered are:

→ Asymmetric Front-End LNAs Gain (**gFi**)
→ Asymmetric Back-End LNAs Gain (**gBi**)
→ Asymmetric Front-End LNAs Noise (**Nfi**)
→ Asymmetric Back-End LNAs Noise (**nBi**)
→ phase errors at the level of the Front-End LNAs **φFi**
→ phase errors at the level of the Back-End LNAs **φBi**

	r1	r2	d1	d2	dr1	dr2	dd1%	dd2%	r1-r2%	d1-d2%
Nominal	0,9276	0,9276	0,013759	0,013758	0,000	0,000	0,00	0,00	0,00	0,00
TX+1K	0,8972	0,8972	0,020201	0,020201	-3,279	-3,279	46,8	46,8	0,00	0,00
Nf1-6%	0,9288	0,9288	0,013759	0,013758	0,126	0,126	0,00	0,00	0,00	0,00
Nf2-6%	0,9288	0,9288	0,013759	0,013758	0,126	0,126	0,00	0,00	0,00	0,00
nb1+10%	0,9276	0,9276	0,013759	0,013758	0,000	0,000	0,00	0,00	0,00	0,00
nB2+10%	0,9276	0,9276	0,013759	0,013758	0,000	0,000	0,00	0,00	0,00	0,00
gF1-10%	0,9228	0,9228	0,013759	0,013758	-0,520	-0,520	0,00	0,00	0,00	0,00
gF2-10%	0,9323	0,9323	0,012383	0,012383	0,507	0,507	-9,99	-9,99	0,00	0,00
gB1-10%	0,9276	0,9276	0,012383	0,013758	0,000	0,000	-9,99	0,00	0,00	-9,99
gB2-10%	0,9276	0,9276	0,013759	0,012383	0,000	0,000	0,00	-9,99	0,00	9,99
φB1=2°	0,9276	0,9276	0,013751	0,013758	0,000	0,000	-0,06	0,00	0,00	-0,06
φB2=2°	0,9276	0,9276	0,013759	0,013750	0,000	0,000	0,00	-0,06	0,00	0,06
ϑ1=1°	0,9276	0,9275	0,0137482	0,013767	0,006	-0,006	-0,078	0,064	0,011	-0,142
ϑ2=1°	0,9275	0,9276	0,01376762	0,013748	-0,006	0,005	0,064	-0,078	-0,011	0,143

***Table 16** Effect from changing Front End and Back End properties: the changes in terms of R-factor and voltage signal difference (odd – even samples) are reported.). From left to right they are reported for the two coupled BEM diodes (i=1, i=2): R-factors (r_j) ; difference odd-even samples (di); percent variation of the R-factors normalized to the Nominal balanced condition (dr_i);); percent variation of the difference odd-even samples normalized to the Nominal balanced condition (dd_i); asymmetry introduced in the R-*

factor normalized to the nominal R (r1-r2);); asymmetry (d1-d2) introduced in the difference odd-even samples normalized to the nominal difference d_j (in the nominal condition d1 = d2) ;

From Table 16 we can extrapolate that the following non-ideal behaviors are feasible in different ways:

±1% change in R factor:

- changing the gain of the Front End LNAs by 20%.
- changing the Front End LNAs Noise by 30%.
- mixing in different proportions the two above losses.

±1% change in signal difference (odd-even):

- modifying by 1% the Gain of the Front End LNA corresponding to the active phase switch.
- modifying by 1% the Gain of one of the two Back End LNAs.

Symmetry in R factors (between the two coupled diodes) :

No way to be induced playing with any of the parameters considered.

±1 % asymmetry in signal difference (odd-even, between the two coupled diodes) :

- modifying by 1% the Gain of one of the two Back End LNAs.

Phase errors up to 2° in the Front End or in the Back End amplifiers produce only marginal changes in the in signal difference (odd-even) , and in the R-factors, respectively lower than 0,15% and 0,01%.

3.5 The in Flight Setup

This section is aimed at verifying the LFI28 behavior basing on a reasonable guess of the above parameters in the default setup. Our purpose is to verify that also a rough representation of the instrument setup, based on evidences from some on-ground and in-flight CPV tests, can fit the R behavior.

The signal model was run in two following frames:

- The case of LFI 28S, supposing that sky and Ref Ohmic Losses are as balanced as by design.
- The case of LFI 28M, in the two frames: (i) balanced losses ; (ii) unbalanced losses.

As average properties we used for the amplifiers (**Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.**):

Average Gain of the Front End and of the Back End LNAs.

Average Noise of the Front End and of the Back End LNAs.

The gain unbalance of the coupled *FEM LNAs* plays a fundamental role in pushing up R value. We get it from the PH/SW Tuning in CPV, where LNAs are switched on individually . From ratios of the voltages measured at the same BEM diode we can roughly estimate the relative gain of the two coupled LNAs.

EQ (6) $$GF1/_{GF2} = \frac{1}{2}\left[\frac{(V1_{odd}+V1_{even})_{M1=ON}}{(V2_{odd}+V2_{even})_{M2=ON}} + \frac{(V2_{odd}+V2_{even})_{M1=ON}}{(V2_{odd}+V2_{even})_{M2=ON}}\right]$$

The gain unbalance of the paired *BEM LNAs* plays a fundamental role in modifying the signal difference (odd-even samples) in the two paired detectors. Again we get it from the Phase switch Tuning in CPV, where LNAs are switched on individually. From the average ratios of the voltages measured in the two BEM diodes we can roughly estimate the relative gain of the two coupled BEM LNAs.

EQ (7) $$GB1/_{GB2} = \frac{1}{2}\left[\left(\frac{V1_{odd}+V1_{even}}{V2_{odd}+V2_{even}}\right)_{M1=ON} + \left(\frac{V1_{odd}+V1_{even}}{V2_{odd}+V2_{even}}\right)_{M2=ON}\right]$$

EQ (6) and EQ (7) are calculated under phase switch nominal bias conditions neglecting second order contributions (resulting from the phase switch tuning itself) to the changes in the absolute voltage from the active phase switch.

Concerning losses at phase switch level, we played with the parameters in Table 14 within the range of the average variation. Average properties were calculated also for LFI28S. The Input parameters used for LFI28M are reported in **Table 17**.

X	TY	TFEM (K)	GF1	GF2	GB1	GB2	nF1	nF2
4.5K	2.7K	20K	31.9 dB	30dB	19,5dB	20dB	10.5K	11.2K
nB1	**nB2**	**eps1**	**eps2**	**epsc**	**ph1F1**	**ph1iF2**	**phiB1**	**phiB2**
320K	290K	<0.04	<0.02	<0.02	<1°	<1°	<1°	<1°

Table 17 Model input parameters used for LFI 28 M

Losses in the Sky Arm were parametrically introduced in the simulation, until the measured value for R (about 0.97) was obtained.

Simulation results are detailed in ***Table 18***.

		r1	r2	d1	d2	dr1	dr2	dd1%	dd2%	r1-r2%	d1-d2 %
1	**LFI 28M DEFAULT**	0,9474	0,9474	0,0123	0,0137	2,13	2,13	-9,99	0,00	0,000	-11,11
2	**eps1=0.02**	0,9501	0,9450	0,0117	0,0143	2,42	1,88	-14,92	4,47	0,549	-21,55
3	**eps1=0; eps2=0.037**	0,9430	0,9525	0,0134	0,0123	1,66	2,68	-2,52	-10,17	-1,021	8,50
4	**eps1=0; eps2=0; epsc=0.02**	0,9470	0,9470	0,0123	0,0137	2,09	2,09	-10,00	0,00	0,001	-11,11
5	**eps1=0.03;eps2=0; epsc=0.02**	0,9512	0,9434	0,0113	0,0146	2,54	1,70	-17,41	6,72	0,833	-26,81
6	**same as 5; IL_sky=0.1dB**	0,9644	0,9566	0,0083	0,0113	3,96	3,12	-39,52	-17,84	0,835	-24,08

7	**same as 5; IL_sky=0.13dB**	0,9682	0,9604	0,0074	0,0103	4,37	3,54	-45,96	-25,00	0,837	-23,29
8	**same as 5; IL_sky=0.15dB**	0,9707	0,9629	0,006	0,0096	4,64	3,81	-50,21	-29,72	0,837	-22,76

Table 18Model output results for LFI28when Sky arm Insertion loss and phase switch attenuation are parametrically changed from 0. The default condition considers the FEM/BEM parameters in Table 17.

3.6 Analysis of Results obtained

Just applying our best guess of LNAs GAIN unbalance and playing with differential Losses at phase switch level:

(i) R-factor increase up to more than 0,95

(ii) A slight R asymmetry is introduced between the two paired BEM diodes (about 0,01 in R units). A similar increasing is not expected instead for LFI28S, due to the good balancing of the FEM LNAs gains (1.9 dB the difference in M channels against 0.2 dB in the S channels).

Moreover:

it was possible to increase R factor to higher than 0,97 just assuming Ohmic excess larger than 0,13 dB in the sky arm. This does not modify the R asymmetry measured for the two paired BEM outputs.

The Reference Test part 2 (CRYO 02) performed in CPV can provides a further confirmation of point (ii): the asymmetry simulated possibly caused by slightly different losses in the phase switches is compatible with what measured when changing the polarization of the still phase switch during the test. This change causes a small swap in the R-asymmetry between the two paired outputs (the relative variation is about 1.5%). This is mostly evident when A/C switching is actively commanded and polarization is changed from 0 to 1 in the B/D phase switches (steps 1 and 2 of the Test procedure)

	A/C SWITCHING		**B/D SWITCHING**	
	STEP1 (B/D -0)	STEP2 (B/D -1)	STEP3 (A/C -0)	STEP4 (A/C- 1)
M	1,010	0,994	1,023	1,024
S	1,006	0,991	1,017	1,028

Table 19 Reference Test performed during CPV: R1/R2 ratio is displayed for each of the PH/SW configurations tested along the 4 steps. R1 refer to diode 1 (V1_odd/V1_even), R2 follows the same rule for diode 2.

The larger insertion loss supposed for the sky M arm is a realistic number. In fact, insertion loss 0,15 dB (corresponding to about 3,5%) higher than specifications (the requirement is IL<0,15 dB) is compatible with the hypothesis of a degradation of the Hybrid or of the OMT with time. Just to address a possible explanation, it is worth reminding the problem occurred with gold plating during the test campaign of the 30 and 44 GHz Front Ends Flight Modules (2006), requiring a reworking of all the devices in order to guarantee the nominal performance (uniformity of surface roughness). It does not mean that imperfect or degraded gold plating is automatically responsible of that, but that it could easily explain losses higher than nominal.

3.7 Possible effects on signal polarization

From the above results we noticed that some of the effects considered in Table 15 and in Table 16 produce non –negligible effects in terms of differential data ($V_{DIFFi}= V_{Skyi} - R_i \cdot V_{REFi}$) . It means that there are non-ideal effects able to increase or decrease V_{DIFF} of just one or of both the coupled diodes acting in the same direction or in opposite directions.

In fact, in the case of a SKY signal loss of 3% just in M-arm we are over-estimating any fluctuation coming from sky, and we are adding a roughly constant term (supposed, at the first order, the FEM temperature to be stable):

EQ (8)

$$P_{diff}(i) \propto \left((1-Loss)\cdot V_{skyi}(t) + Loss\cdot V_{FEM}\right)^2 - \left(\frac{\langle(1-Loss)\cdot V_{skyi}(t) + Loss\cdot V_{FEM}\rangle}{\langle V_{refi}(t)\rangle}\right)^2 \cdot V_{refi}(t+\Delta t)^2$$

This error does not null also when we average over the two coupled diodes *i=1,2* :

$$P_{DIFF} = \frac{P_{diff}(1) + P_{diff}(2)}{2}$$
$$\propto (1-Loss)^2 \cdot \left(\frac{V_{sky1}(t)^2 + V_{sky2}(t)^2}{2}\right) + (Loss)^2\cdot T_{FEM} + (1-Loss)\cdot Loss\cdot V_{FEM}\cdot \frac{\left(V_{sky1}(t) + V_{sky2}(t)\right)}{2}$$
$$- \sum_{i=1}^{2} \frac{R_i^* \cdot V_{refi}(t+\Delta t)^2}{2}$$

EQ (9) with: $R_i^* = \left(\frac{\langle(1-Loss)\cdot V_{skyi}(t) + Loss\cdot V_{FEM}\rangle}{\langle V_{refi}(t)\rangle}\right)^2$

It means that, when we subtract between the average V_{DIFF} calculated from Main and Side arms we get at some level (to be quantified) a systematic spurious polarization depending on the LOSS term.

In addition to this, we must consider also the case of errors introduced in V_{DIFF} from non-ideal losses at phase switch level (when any of ε_{A1}, of ε_{A2}, of ε_{Ac} is non-null) ; in detail, when of $\varepsilon_{A1}, \neq \varepsilon_{A2}$, errors of opposite sign are introduced in V_{DIFF} from the two coupled diodes, as clearly evident from Table 15 (see the last column 'd1-d2 %') .

The rigorous analytic formulation is something beyond the scope of this note, and will require a further dedicated effort. However, we just want to stress the fact that when in EQ (5) $\varepsilon_{A1}, \neq \varepsilon_{A2}$, we get from the two coupled diodes:

EQ (10) $\mathrm{P_{diff}(i)} \propto a(i)\cdot \mathrm{P_{diff}(i)}^*\left(1 + \mathrm{e}^{\mathrm{i}\vartheta_{\mathrm{ij}}}\epsilon_{\mathrm{Aj}}\right)$

where, *a(i)* is a proportionality coefficient and $P_{diff}(i)^*$ is the value obtained considering null losses $\varepsilon_{A1}= \varepsilon_{A2}$. Following the previous rule, i=1,2 represent the diode , j=1,2 corresponds to the phase switch status and the phase term ϑ_{ij} is equal to $\vartheta 1$ (nominally 0) for i=j and equal to $\vartheta 2$ (nominally π) for i≠j.

Hence, it is possible that , when averaging over the two coupled diodes, we are indeed biasing the result depending on the weights used. This is in principle true also for the case of a simple arithmetic average, where the two $P_{diff}(i)^*$ terms have equal weights w_1=w_2=0.5 . However, in this last case, the residual error should be lower, because of a compensation of the two anti-correlated effects, and proportional to the ratio of the coefficients *a(i)* .

We plan in the next step to consider two following frames obtained when averaging $P_{diff}(1)$ and $P_{diff}(2)$:

- equal weights are assigned

- assign weights proportional to asymmetries at phase switch level or at Back-End gain level (possibly getting the information from differenced data at level of single diodes) instead of based on the Rms of each diodes, as is the up to date baseline (values are reported in Table 20)

LFI28M-00	**0.553227696**
LFI28M-01	0.446772304
LFI28S-10	0.467677355
LFI28S-11	0.532322645

Table 20 weights used up to date for LFI 28. It is worth noting the symmetry of weights adopted for the Main and for the Side arm diodes, suggesting a possible role of the active phase switch.

4. Conclusions

LFI28-M shows R-factors larger than its paired radiometer LFI28-S, and generally larger than the values expected when considering the system temperature: as a result, noise temperatures much higher than expected come out when calculated from R factors. However independent methods based on Y factor or on signal RMS provide much smaller noise temperature, in line with the expectation.

This puzzling and apparently inconsistent frame is analyzed in this note. In detail we studied the origin of the behavior (when it was observed for the first time) and its possible causes. We based on results from the Ground Test campaign in CSL at satellite level (2008), on CPV Test campaign (2009) and on flight data acquired during the normal operations. We found that R factors have been showing this anomalous excess at least since the beginning of the ground test campaign at Satellite Level performed in CSL. Although the instrument was tested under very different environmental and setup conditions, we could not find any data stream where R seem to depart from this behavior. We also checked whether the effect could have been possibly triggered by other instrumental instabilities (such as: oscillations at Front End or Back End amplifiers level , also in other channels already known to be coupled with LFI28) but results are in contradiction with this hypothesis.

Hence we proceeded with disentangling the possible causes of high R values, analyzing what can cause either (i) signal loss from reference load arm and (ii) signal excess from the sky arm.

We started with possible mismatching at level of Reference Load arm (occurring at some place between the load and the Hybrid) . Using multiple approaches we concluded that hypothesis would require mismatching of about 4 dB; this value was considered unbelievable basing just on misalignments (horn-load) and / or on cracks at the level of the load / antenna system. Beside of these considerations supported by results from dedicated ground tests at 4K Reference Load unit level, this hypothesis is ruled out by calculating the calibration constant of the M radiometer. In fact, results from independent tests performed during the CSL test campaign and during CPV demonstrated that the calibration constant is the same both when calculated from change in the sky and in the reference load input signal, without regard to the cause of the signal changes (HFI 4K Unit heat lift test, HFI 4K control failure, Sky load Helium Refilling, Dipole modulation, etc..). This convergence would be impossible in the case of a 4 dB loss in the reference load signal: in fact, the gain constant from reference Load changes would be expected at least 40 percent lower than the value calculated from sky signal changes.

Secondary we analyzed the possibility of signal excess at the level of sky arm. A signal excess was modeled through an insertion loss occurring before the Front End LNAs, in the sky arm (sky arm in the Hybrid or OMT) . In fact, any loss is able at the same time to (i) attenuate the sky signal, (ii) introduce a signal excess proportional to the Front End Unit temperature. We obtained that a loss of about 0,2 dB (4,5%) is enough to increase R-factor up to 0,97. This excess in the insertion loss could have been created by *aging* effects or by other anomalies occurred in the hybrid or in the OMT. As an example, we reminded the problem involving the metal gold plating occurred during the Flight model ground tests, requiring the whole reworking of 30 GHz and 44 GHz FEM units.

However, the insertion Loss, alone, could not give reason of the two slightly different R and noise temperatures between the two coupled M – diodes.

As the last, we calculated the effects coming from other asymmetries at FEM and BEM level , between LNAs Gain, LNAs noise, Phase switch Insertion Loss, phases (of phase switch and LNAs). We selected those effects mostly affecting R-factor in terms of absolute value and unbalancing when calculated from the two coupled diodes. In detail , we found that the largest contribution to increasing R is given by differential Gains of the two coupled Front End LNAs; the R unbalancing is provided by losses at phase switch level in the arm containing the active phase switch controlled at 4KHz. Gain unbalancing can reasonably explain R values up to 0,95, phase switch losses can explain asymmetries consistent with the numbers measured.

As a final test we tried to apply what learned from the previous analysis to a realistic in-flight setup. In detail, we extracted the required information regarding the average noise and gain of LNAs from the specification documents while we tried to inter-calibrate the asymmetries (FEM and BEM gain, differential losses of phase switches) basing on results from available on-ground or in-flight tests. These numbers were used as input for the signal model. The final result was that the in-flight setup is in principle able to explain the large R-factor and the slightly different R’s of the two coupled diodes, provided that a mix of two combined effects is considered: insertion loss of at least 0,13 dB (2,5%) larger than specifications; gain unbalancing of about 1.9 dB in the two M- coupled FEM LNAs (consistent with what measured from the phase tuning test) Insertion losses at phase switch level (lower than 5%) within the range of the values independently measured from the phase switch tuning tests.

All the above considerations convinced us that:

- Large R factors can be considered something 'expected' also under a realistic frame: the model mixing extra-losses in the sky arm together with differential insertion losses in the phase switch and with differential gains of the FEM LNAs is able to explain the R values measured.
- In principle high R's do not denote major anomalies at instrument level.

Nevertheless some non-ideal effects contributing to this frame could contribute to induce some spurious polarization when the difference between the Main and Side signals is calculated. A preliminary study was performed showing that a more appropriate weighting of signals in the two coupled diodes of each Radiometer arm could contribute to mitigate this effect. This part of the investigation will be the next step of this work.

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