TITLE: # RCA_SPR Test Report on the 30 GHz RCA QM

DOC. TYPE: TECHNICAL NOTE

PROJECT REF.: PL-LFI-PST-TN-065 **PAGE:** I of IV, 19

ISSUE/REV.: 1.0 **DATE:** May 2005

Prepared by	F. VILLA LFI Project System Team	Date: Signature:	May 10th, 2005
Checked by	A. MENNELLA L. STRINGHETTI LFI Project System Team	Date: Signature:	May 10th, 2005
Agreed by	C. BUTLER LFI Program Manager	Date: Signature:	May 10th, 2005
Approved by	N. MANDOLESI LFI Principal Investigator	Date: Signature:	May 10th, 2005

DISTRIBUTION LIST

Recipient	Company / Institute	E-mail address	Sent
T. PASSVOGEL	ESA – Noordwijk	Thomas.Passvogel@esa.int	Yes
G. CRONE	ESA – Noordwijk	Gerald.Crone@esa.int	Yes
J. MARTI-CANALES	ESA – Noordwijk	Javier.Marti.Canales@esa.int	Yes
J. TAUBER	ESA – Noordwijk	Jan.Tauber@esa.int	Yes
N. MANDOLESI	IASF/INAF – Sez. Bologna	mandolesi@bo.iasf.cnr.it	Yes
C. BUTLER	IASF/INAF – Sez. Bologna	butler@bo.iasf.cnr.it	Yes
M. BERSANELLI	UniMI – Milano	marco.bersanelli@fisica.unimi.it	Yes
M. BALASINI	ALENIA SPAZIO – LABEN	Balasini.m@laben.it	Yes
G. CAFAGNA	ALENIA SPAZIO – LABEN	Cafagna.g@laben.it	Yes
M. MICCOLIS	ALENIA SPAZIO – LABEN	miccolis.m@laben.it	Yes
P. LEUTENEGGER	ALENIA SPAZIO – LABEN	Leutenegger.p@laben.it	Yes
LFI CALIBRATION TEAM			Yes
LFI CO-I's			Yes
LFI Local PROGRAM MANAGER			Yes
LFI SPCC	IASF/INAF – Sez. Bologna	lfispcc@bo.iasf.cnr.it	Yes

CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
1.0	May 10, 2005	All	First Issue of the Document	===

TABLE OF CONTENTS

1 INTRODUCTION AND SCOPE

"Measurements of the radiometers' bandpasses are necessary for the analysis of in-flight data. Unlike the radiometric gains and offset, which are calibrated in flight, bandpass measurements must be made before launch"

[RD 1] – WMAP team

Band pass measurements are required by the calibration plan [AD1], which reports also the specification of the test:

ID – RCA_SPR

TEST NAME – RF Spectral Response

TEST DURATION – Estimated data taking time: 3 hours (Note that this test requires warmup-cooldown of facility – NOT included)

TEST PURPOSES – Measure the radiometer spectral response within the operational band. The shape of the band is needed, i.e. only a relative measurement is performed.

CONCEPTUAL DESCRIPTION – The spectral response is measured at RCA level by injecting a calibrated RF monochromatic source into the sky horn sweeping through the band. It is planned to perform this test at RCA level only, in cryogenic setup with the source coupled to the feedhorn aperture. The frequency of the input RF source is swept over the band of interest and the measured radiometer DC outputs are correlated with the input frequency to produce the RF frequency response. This test is done using the nominal operating mode and difference data.

NUMBER OF RCAs – ALL QM , ALL FM

OUTPUT PARAMETERS – Radiometer band shape (relative) as a function of frequency

ACCURACY – TBD

Measurements will be made by injecting a small signal into the sky horn and recording the radiometric response. For LFI radiometers, the basic idea is inject a narrow band signal *onto the sky horn*, **calibrating in this way also the feedhorns and the OMTs**. The signal is sweeping across the bandwidth of the RCA under test, nominally 20% of bandwidth, eventually enlarged to the full waveguide band. The radiometer output will be recorded and the bandpass response will be derived form data.

Scope of this technical note is to report on the RCA_SPR test performed on the LFI 30 GHz RCA Qualification Model.

2 APPLICABLE DOCUMENTS

[AD 1] M. Bersanelli, *Planck–LFI Calibration Plan*, PL–LFI–PST–PL–008 Issue/Rev 1.0 July 2003

[AD 2] LABEN, *Planck LFI 30 and 44 GHz RCA Test and Calibration Plan*, PL–LFI–LAB–PL–010 Rev/Ver 1.0

3 REFERENCE DOCUMENTS

[RD 1] N. Jasorik, et al., *Design, Implementation And Testing Of The Map radiometers,* ApJ Supplement, Vol. 145, pp. 413–436 (2003)

[RD 2] Agilent Technologys, *8360 Series Synthesized Sweepers User's Handbook*, Part No. 08360–90070, 1995

[RD 3] F.Villa, *RCA Swept Source Measurement Setup*, Planck LFI technical note, To be Configured (Draft)

4 MEASUREMENT SETUP

The sketch of the measurement setup is reported in Figure 1.

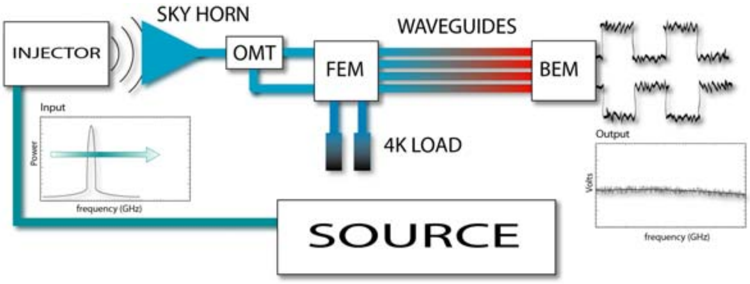


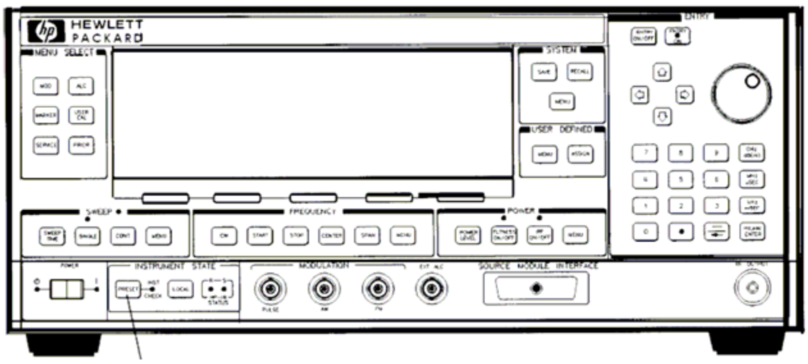
FIGURE 1: **SCHEME OF THE LFI RADIOMETER CHAIN ASSEMBLY PASSBAND MEASUREMENTS**

Here we describe the source, the injector and the waveguide system connecting the both.

4.1 THE SOURCE

The source used during this test has been provided by FRACARRO RADIOINDUSTRIE S.p.A (http://www.fracarro.com) and is composed by:

- *Agilent Synthesized sweeper HP 83650L S/N …*



Huber – Suhner Sucoflex 100 coaxial cable with PC 2.4 mm female coax connectors.
See http://www.hubersuhner.com/ for cable specification.

- *Agilent Male 2.4 mm Coax – WR22 rectangular waveguide transition HP Q281B*

4.2 THE INJECTOR

The injector is composed by a truncated stainless steel WR28 rectangular waveguide inserted in one of the dedicated hole of the RCA sky load and supported by a Teflon cylinder.

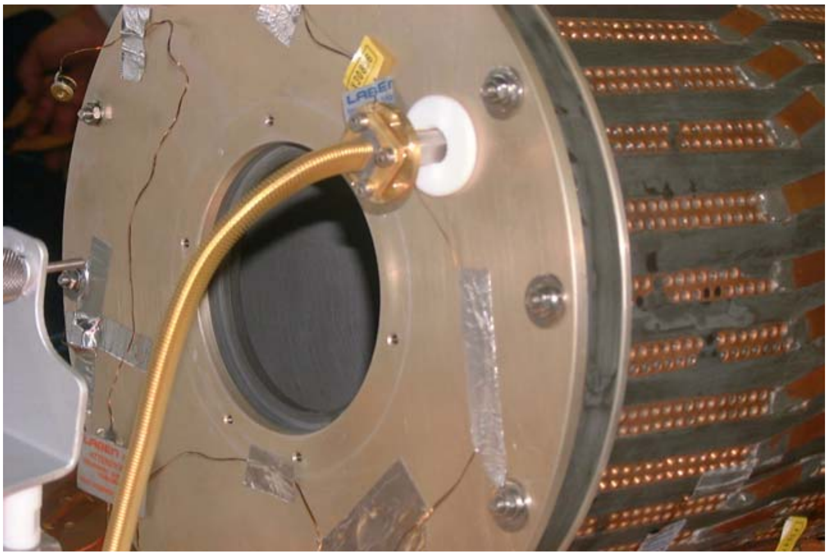


FIGURE 2: INJECTOR CLOSE UP VIEW

4.3 RF TRANSMISSION LINE FROM SOURCE TO INJECTOR

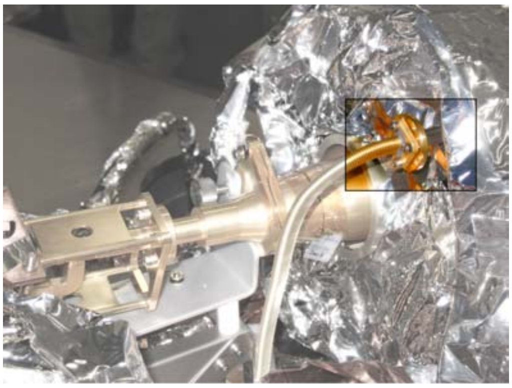


FIGURE 3: LEFT – DETAIL OF THE COAX – WG TRANSITION CONNECTED TO THE FEED THROUGH BY A WAVEGUIDE SECTION; RIGHT – DETAIL OF THE FLEXIBLE WAVEGUIDE END

Starting from the coax – waveguide transition, the transmission line is composed by:

- *A straight section of WR22 copper waveguide connecting the transition to the cryofacility flange*
- *WR28 Waveguide feed through with kapton window to interface the cryofacility to the external environment*
- *A straight section of WR28 stainless steel waveguide acting as a thermal brake*
- *A WR28 flexible waveguide 1 meter long*

At the time of this measurement the WR28 coax–waveguide transition was not used because of the missing coaxial adapter to interface with the RF cable.

4.4 FREQUENCY LIST

Frequency list has been defined and inserted manually on the sweeper taking advantage of the LIST MENU instrument capabilities.

List Menu

Function Group FREQUENCY

Menu Map 2

Description This softkey allows access to the frequency list functions.

Auto Fill Incr	Automatically creates a frequency list using the user-specified increment value.
Auto Fill #Pts	Automatically creates a frequency list containing a user-specified number of points.
Auto Fill Start	Allows the entry of a start frequency for the frequency list.
Auto Fill Stop	Allows the entry of a stop frequency for the frequency list.
Delete Menu	Reveals the frequency list delete menu.
Enter List Dwell	Allows the entry of a dwell time for a frequency point in the frequency list.
Enter List Freq	Allows the entry of a frequency point into the frequency list.
Enter List Power	Allows the entry of an ALC output power correction value for a frequency in the frequency list.
Global Dwell	Automatically sets the dwell time for all points in the frequency list to a user-specified value.
Global Offset	Automatically sets the ALC output power correction value for all points in the frequency list to a user-specified value.
Pt Trig Menu	Reveals the frequency list in the point trigger menu.

A frequency list consists of two or more frequency points. A frequency point can be any frequency value within the specified frequency range of the synthesizer and must be entered before a value for either ALC output power offset or dwell time is accepted. The maximum number of frequency points in a frequency list is 801.

Creating a Frequency List

There are two methods of constructing a frequency list:

1. Use the Enter List Freq softkey to begin entering frequency points. The list will be generated in the order the values are entered.
2. If the minimum and maximum frequencies of the synthesizer frequency range are not the endpoints desired for the frequency list,use the Auto Fill Start and Auto Fill Stop softkeys to define the frequency list endpoints. Then, use either the Auto Fill Incr or Auto Fill #Pts softkeys to create the list. A list created by this method is ordered with the lowest frequency as the first point and the highest frequency as the last point of the frequency list.

Editing Frequency Points

To add a frequency point to the list, place the active entry arrow --> where you want the next frequency point to appear. The frequency point is added directly after the value indicated by the arrow.

Lists created by the Auto Fill method are appended to an existing list much the same way frequency points are added to a list. The newly created list is added between the frequency point indicated by the active entry arrow and the point directly after it.

Note If adding a new list of frequencies causes the existing list to exceed the maximum number of frequency points allowed (801), the new list is not appended to the existing list. The error message TOO MANY LIST PTS REQUESTED is displayed.

Specifically, for each frequency point (801 maximum) the `OFFSET` and the `DWELL` need to be defined. They are the power offset in dB with respect the Output Power Level set in the instrument and the persisting time of a single frequency point, respectively.

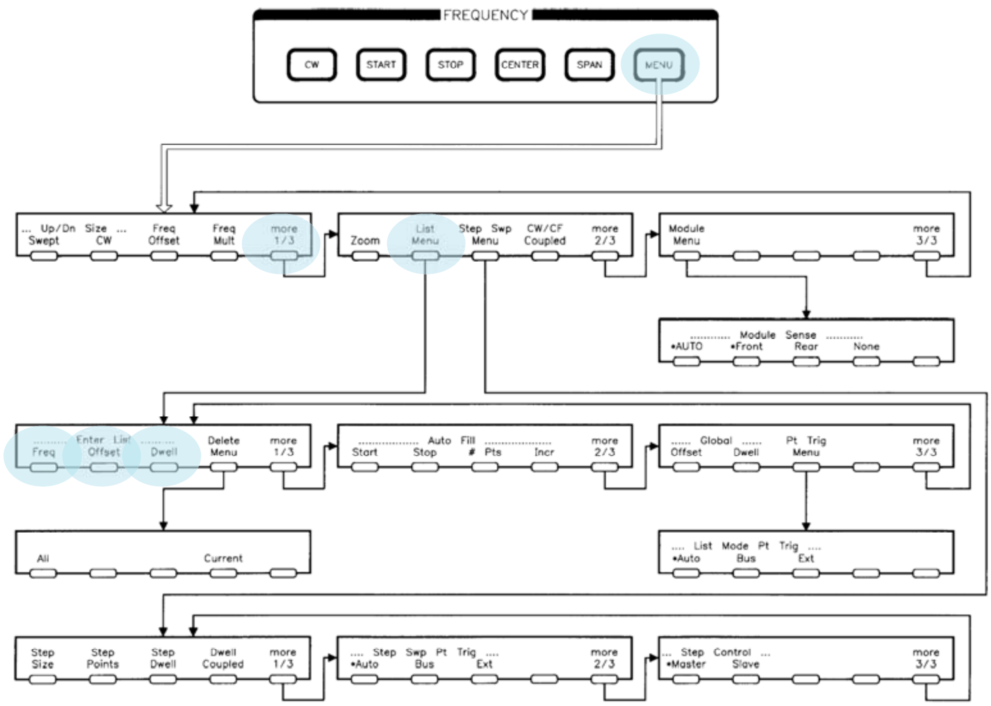


FIGURE 4: MAP OF THE FREQUENCY MENU OF THE AGILENT SWEEPER USED IN THIS TEST

TABLE 1: DEFINITION OF THE LIST FREQUENCY. THE STEP PARAMETER IS THE FREQUENCY STEP.

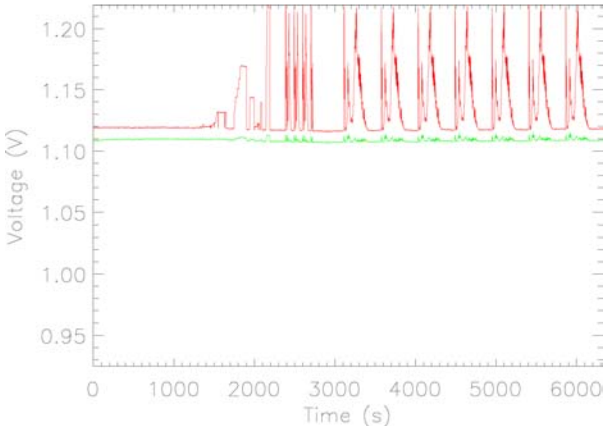
POINT ID	FREQUENCY	OFFSET [DB]	DWELL [MSEC]
1	30	+6	3000
2	30	+0	3000
3	30	+3	3000
4	30	+0	3000
5	26.5 (*Fstart*)	+3	3000
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
$N = \frac{Fstop - Fstart}{step} + 1$	40.0 (*Fstop*)	+3	3000

5 DATA STEAM

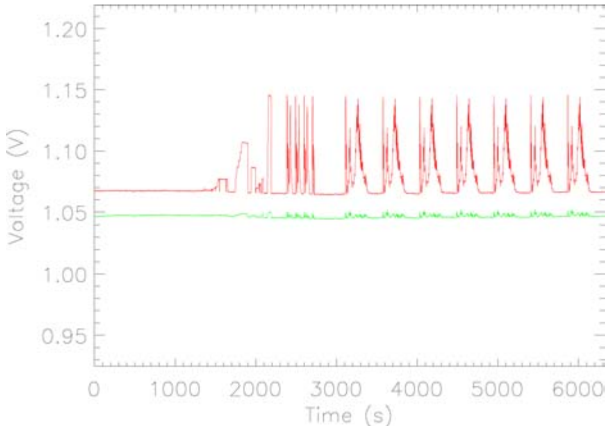
Data have been taken on 10th March 2005 starting at 15h 21m 21s, ending at 17h 06m 48s in Universal Time and stored in five files formatted and named according to Rachel definition:

```
030LFI28_RCA_QM_SPR_200503101619.AUX.fits
030LFI28_RCA_QM_SPR_200503101619.CFG.fits
030LFI28_RCA_QM_SPR_200503101619.DAT.fits
030LFI28_RCA_QM_SPR_200503101619.ENV.fits
030LFI28_RCA_QM_SPR_200503101619.LOG.fits
```

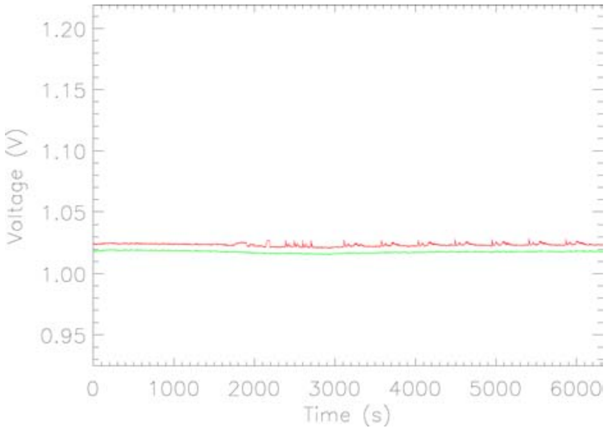
Here, the plot of AUX files for all the four detectors:



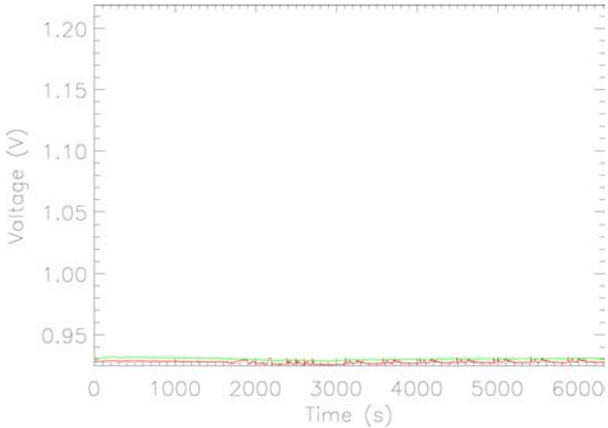
Plot of the data stream for Detector 1



Plot of the data stream for Detector 2



Plot of the data stream for Detector 3



Plot of the data stream for Detector 4

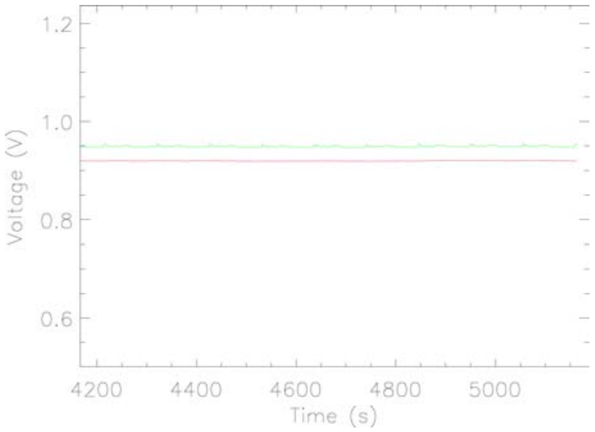
FIGURE 5: PLOT OF THE DATA STREAM AT CRYO TEMPERATURE

Since the injector (truncated waveguide) has been mainly aligned with one polarization, detector 1 and 2 are more sensible to swept source test than the detector 3 and 4.

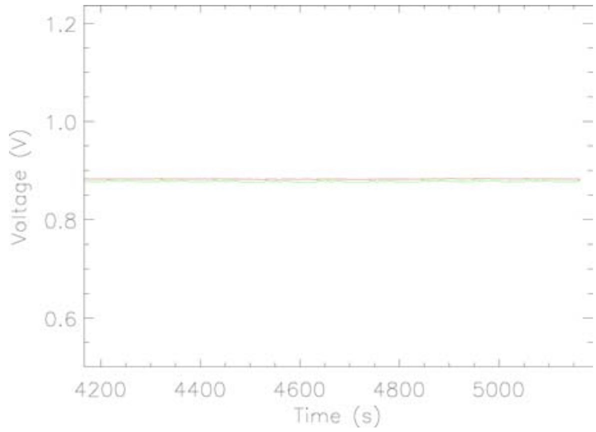
To check this behavior, the data steam obtained at warm temperature with the injector rotated by 90 degrees is reported. It is evident that in these data the most sensible detectors are 3 and 4 instead of 1 and 2. Warm

RCA_SPR was not foreseen by the RCA test plan and was performed in order to demonstrate the goodness of the SPR test setup.
The SPR data at warm temperature where obtained on 1st March 2005 starting at 17h 15m 52s and ending at 18h 41m 55s in Universal Time.
The files are the following

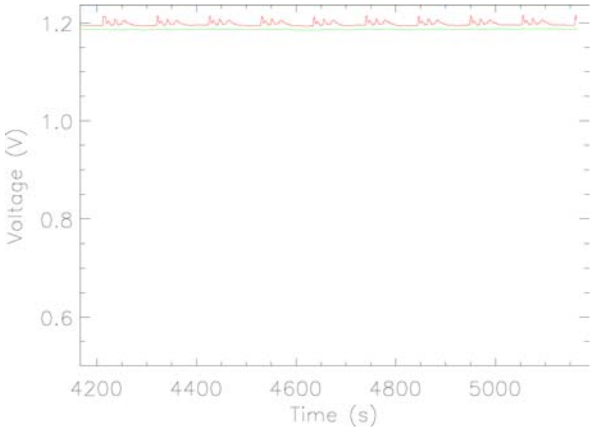
```
030LFI28_RCA_QM_XXX_200503011814.AUX.fits
030LFI28_RCA_QM_XXX_200503011814.CFG.fits
030LFI28_RCA_QM_XXX_200503011814.DAT.fits
030LFI28_RCA_QM_XXX_200503011814.ENV.fits
030LFI28_RCA_QM_XXX_200503011814.LOG.fits
```



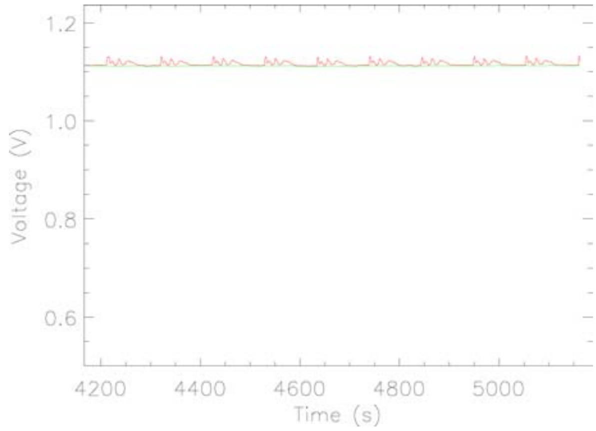
Plot of the data stream for Detector 1 at ambient T



Plot of the data stream for Detector 2 at ambient T



Plot of the data stream for Detector 3 at ambient T



Plot of the data stream for Detector 4 at ambient T

FIGURE 6: PLOT OF THE DATA STREAM AT AMBIENT TEMPERATURE

The data steam is composed by three different "areas" here listed (see Figure 7)

- light blue: search of optimal power level
- mid blue: first set of scan (3 complete scans) with 0.5 GHz in step, hereafter called Run1
- dark blue: second set of scan (7 complete scans) with 0.1 GHz in step, hereafter called Run2

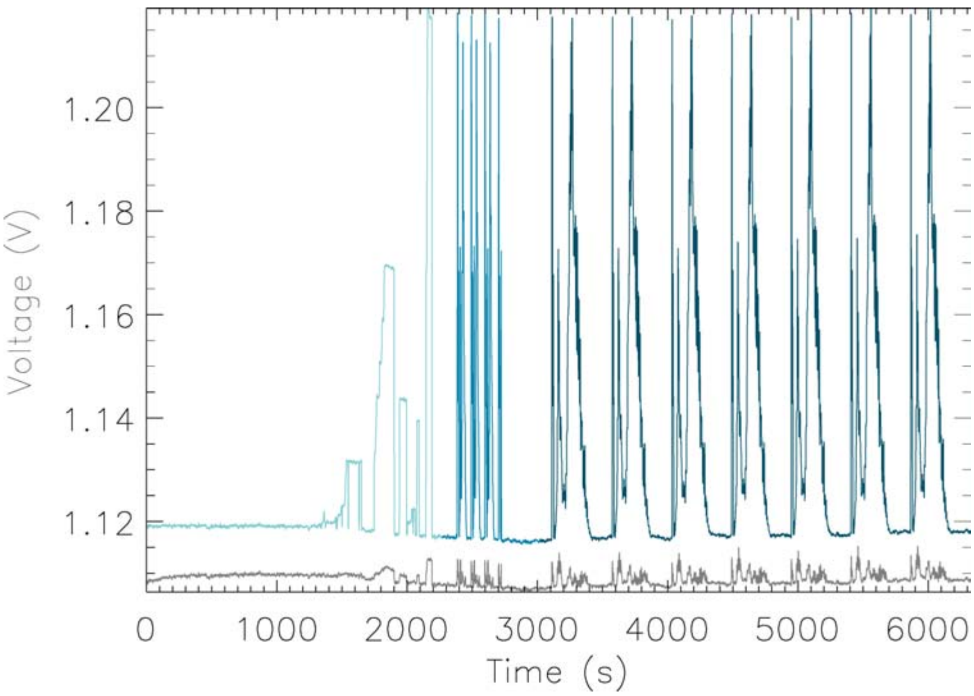


FIGURE 7: DATA STEAM EXPLANATION

The parameters of the two different set of scans are reported in the following tables.

TABLE 2: PARAMETERS OF THE FIRST FREQUENCY SCAN

POWER LEVEL [DBM]………………………………………...	–34 dBm
TRIGGER SEQUENCE [DB]…………………………………	[+6, 0, +3, 0]
TRIGGER FREQUENCY [GHZ]……………………….…...	[30, 30, 30, 30]
TRIGGER TIME [MSEC]…………………………………….	[3000, 3000, 3000, 3000]
START FREQUENCY [GHZ]……………………………....	26.5
STOP FREQUENCY [GHZ]………………………………….	40.0
STEP FREQUENCY [GHZ]………………………………….	0.5
RELATIVE POWER LEVEL [DB]……………………………	+3
TIME [MSEC]………………………………………………	3000

TABLE 3: PARAMETERS OF THE SECOND FREQUENCY SCAN

POWER LEVEL [DBM]………………………………………...	–34 dBm
TRIGGER SEQUENCE [DB]…………………………………	[+6, 0, +3, 0]
TRIGGER FREQUENCY [GHZ]……………………….…...	[30, 30, 30, 30]
TRIGGER TIME [MSEC]…………………………………….	[3000, 3000, 3000, 3000]
START FREQUENCY [GHZ]……………………………....	26.5
STOP FREQUENCY [GHZ]………………………………….	40.0
STEP FREQUENCY [GHZ]………………………………….	0.1
RELATIVE POWER LEVEL [DB]……………………………	+3
TIME [MSEC]………………………………………………	3000

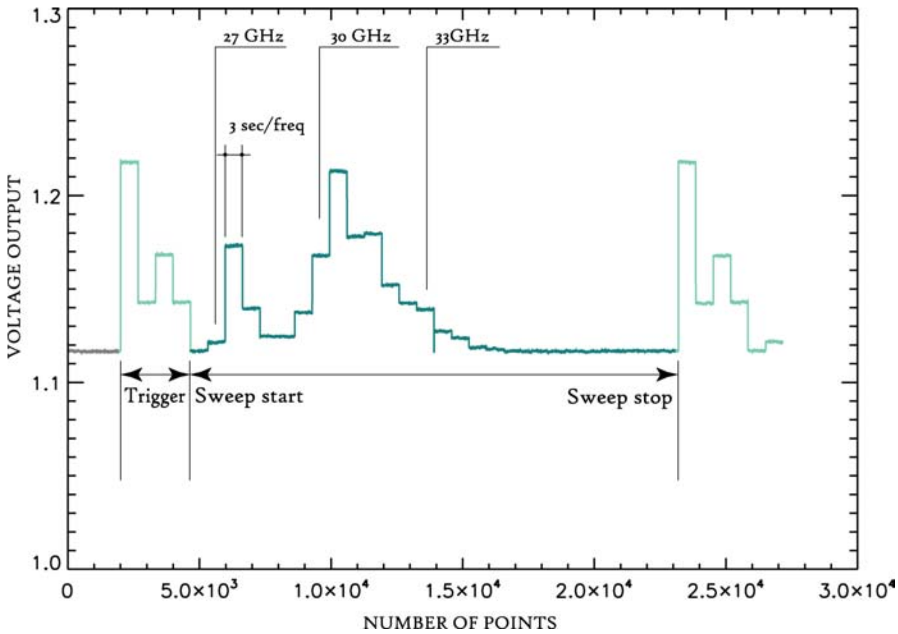


FIGURE 8: EXPLANATION OF A SINGLE SCAN. THE TRIGGER SEQUENCE IS PLOTTED IN LIGHT GREEN, WHILE THE SCAN OF THE RADIOMETER BAND IS PLOTTED IN DARK GREEN. AFTER THAT, ANOTHER TRIGGER SEQUENCE SET THE START OF A SECOND FREQUENCY SCAN.

5.1 COMPARISON BETWEEN THE TWO SCAN RUNS

Here we report on the comparison between the two runs (Run1 & Run2) performed with different frequency Step. In Figure 9 the two swept are reported showing the excellent agreement, as expected. Data analysis has been applied on the Run2 only.

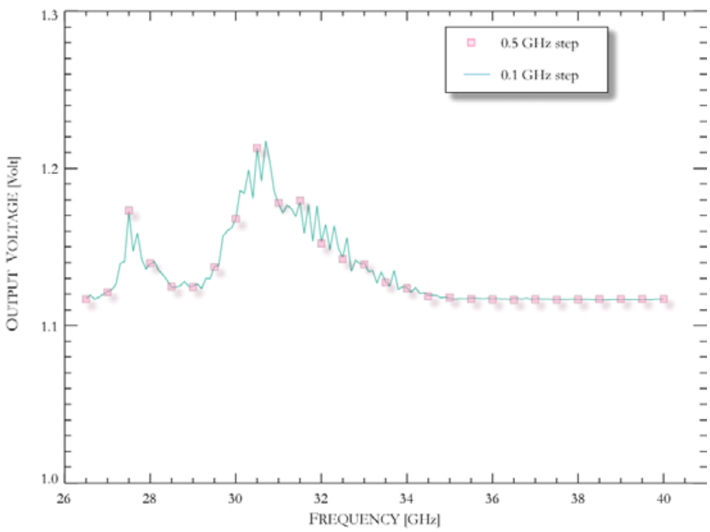


FIGURE 9: COMPARISON BETWEEN SCANS WITH DIFFERENT FREQUENCY STEP ON DETECTOR 1

6 DATA ANALYSIS, CALIBRATION, AND RESULTS

6.1 CALIBRATION AND ANALYSIS

Data analysis concept is reported in annex 1. Method 1 has been applied (see Annex 1).
A RaNA[1] module (`RaNA_spr`) has been developed to analyze the swept source data for all the detectors.
For this test calibration means to calibrate the power response of the RF test chain as a function of the frequency.
Data have been calibrated considering the attenuation of the WR22 waveguide in the 26.5–40 GHz range due to the coax – wg adapter has been used during the test.
From simulation the following attenuation behavior has been applied. It is stressed here that only a relative response is needed.

$$L = \frac{309.31\cdot\left(0.00568 + 8.1989\cdot 10^{-6}\cdot \nu^2\right)}{\sqrt{\nu\cdot\left(0.00144093\cdot\nu^2 - 1\right)}}\left[\frac{dB}{meter}\right]$$

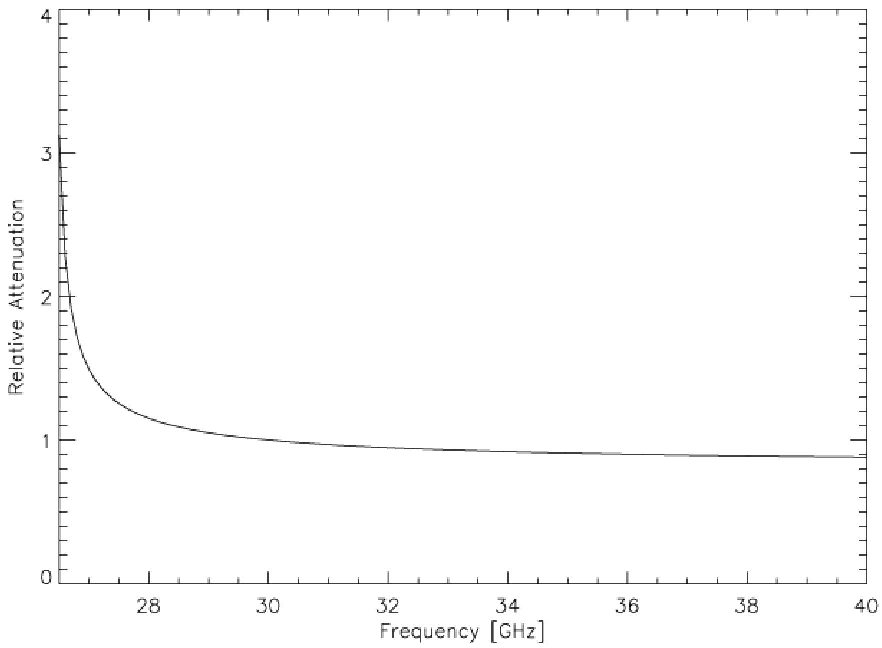


FIGURE 10: RELATIVE (DECIMAL) ATTENUATION (1/L) OF THE RF TEST CHAIN USED A CALIBRATION CURVE. THE CURVE IS NORMALIZED TO 1 AT 30 GHZ

[1] RaNA is The radiometer analyser tool http://lucifer.mi.iasf.cnr.it/web/rana

6.2 RESULTS

Here the results as obtained with the `RaNA_spr` module. The band response, reported in dB, has been normalized at the value at 30 GHz. The following plots are referred to each of the 4 detectors and have been obtained using the second sweep with 0.1 GHz of step.
In addition a comparison between different swept has been reported.

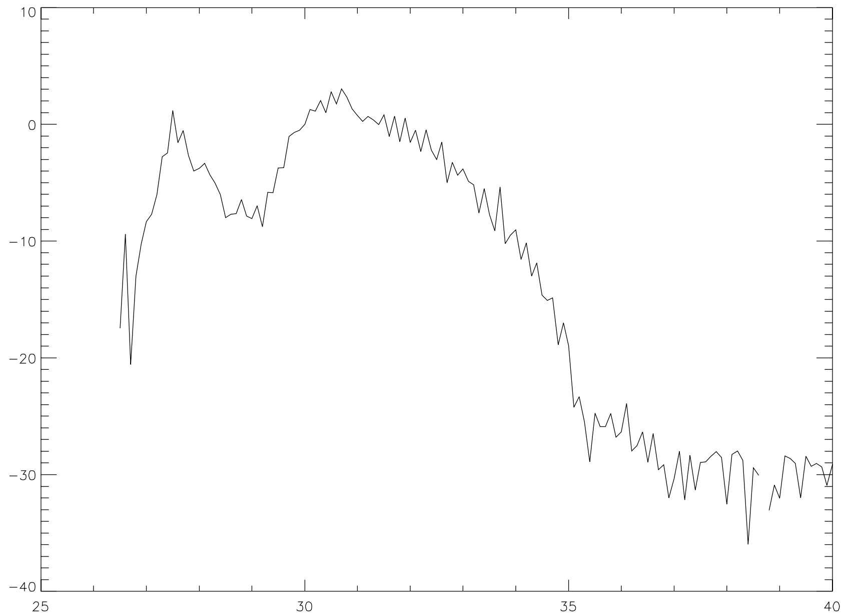


FIGURE 11: DETECTOR 1 CALIBRATED BANDPASS SHAPE

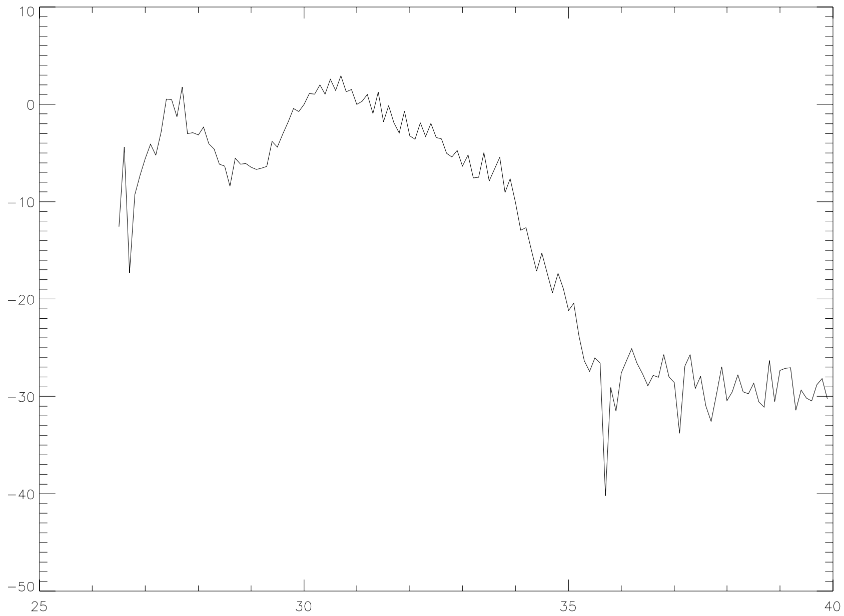


FIGURE 12: DETECTOR 2 CALIBRATED BANDPASS SHAPE

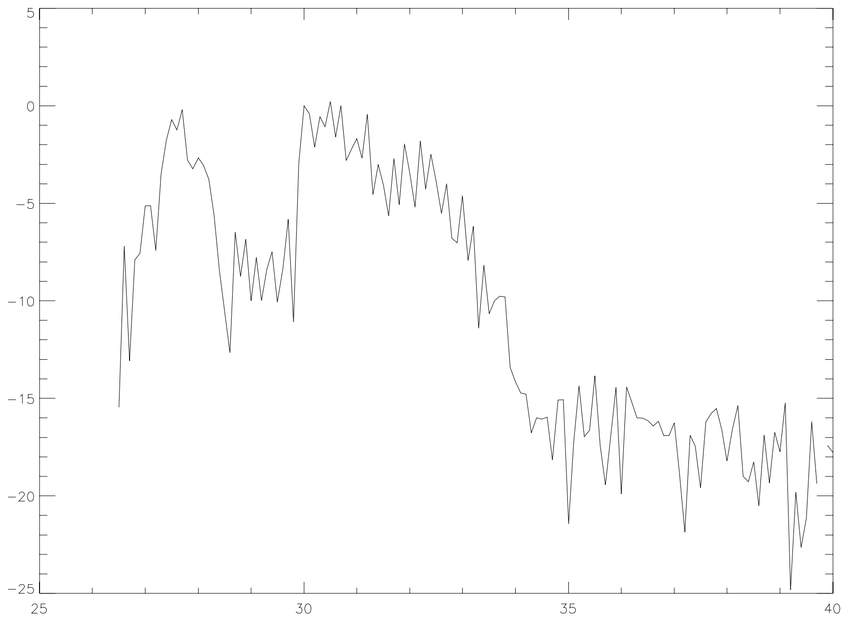


FIGURE 13: DETECTOR 3 CALIBRATED BANDPASS SHAPE

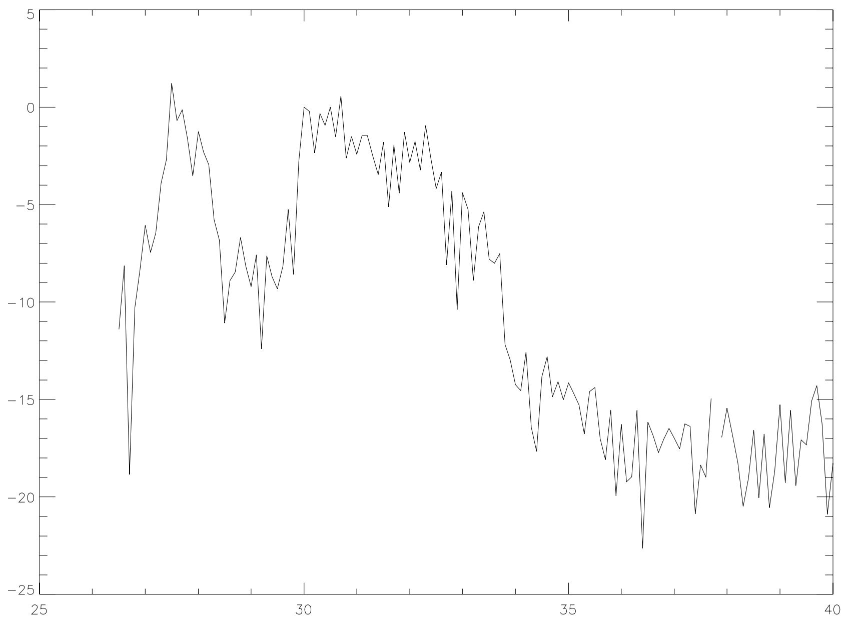


FIGURE 14: DETECTOR 4 CALIBRATED BANDPASS SHAPE

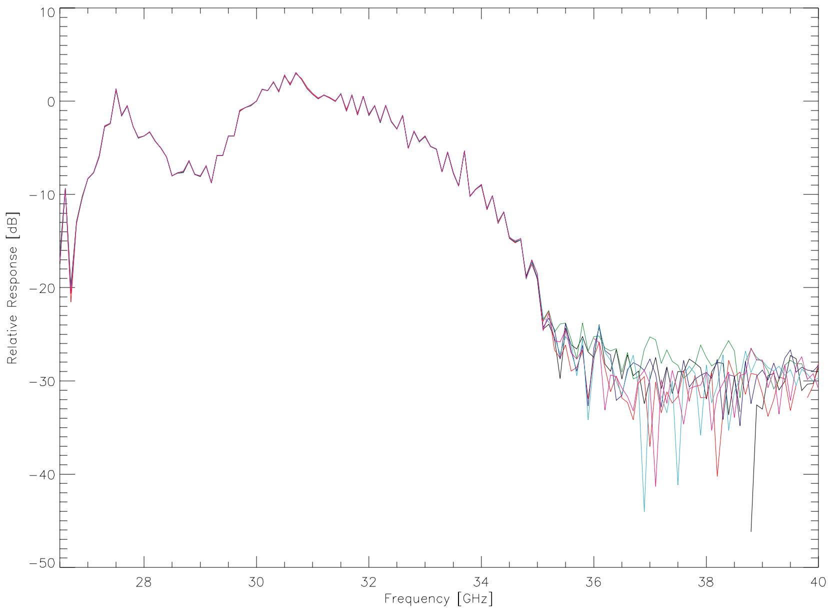


FIGURE 15: DETECTOR 1 CALIBRATED BANDPASS SHAPE – COMPARISON BETWEEN DIFFEREN SWEPT

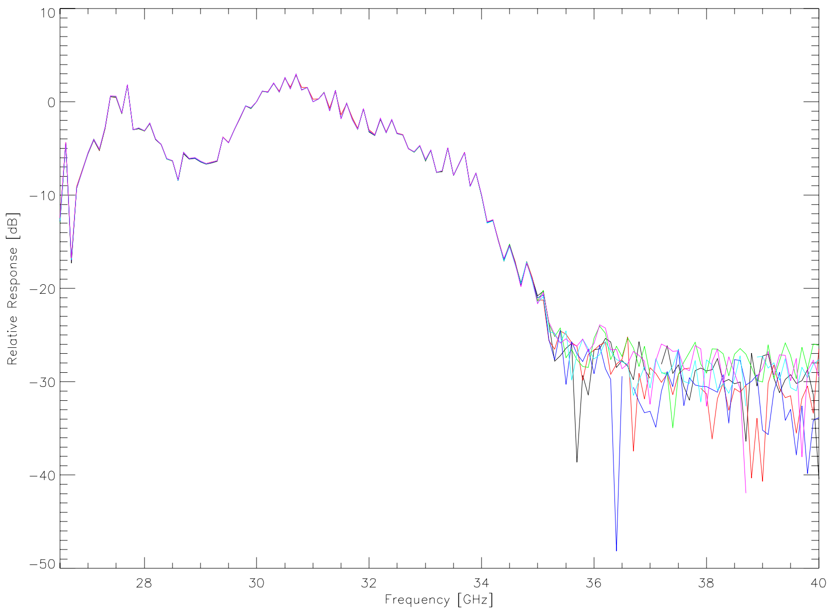


FIGURE 16: DETECTOR 2 CALIBRATED BANDPASS SHAPE – COMPARISON BETWEEN DIFFEREN SWEPT

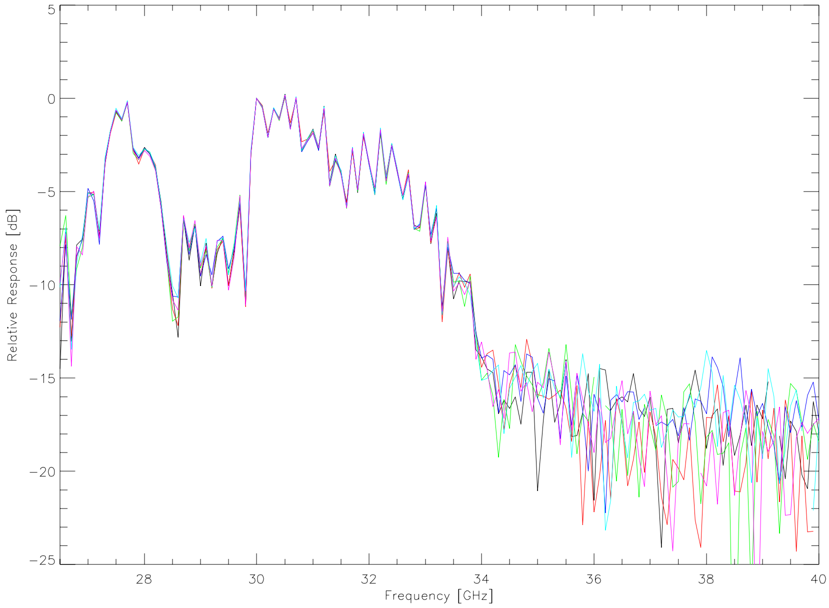


FIGURE 17: DETECTOR 3 CALIBRATED BANDPASS SHAPE – COMPARISON BETWEEN DIFFEREN SWEPT

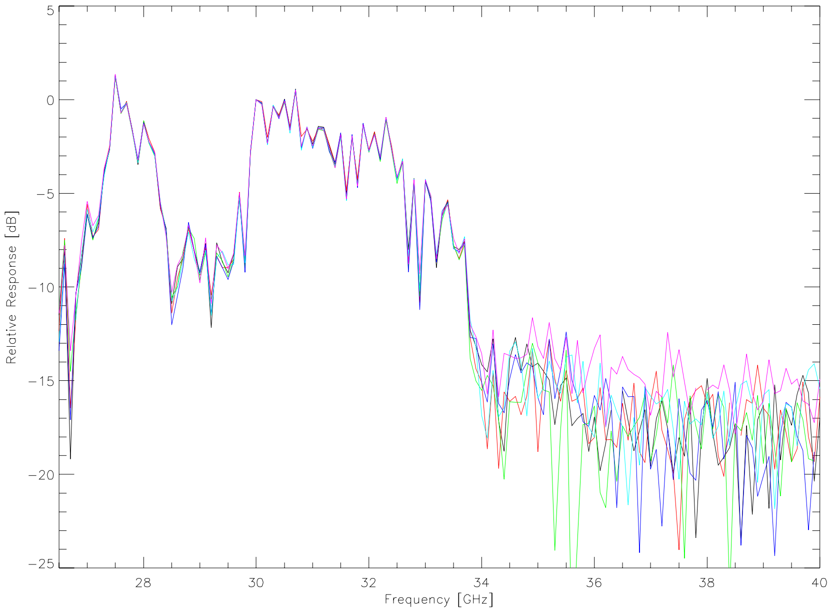


FIGURE 18: DETECTOR 4 CALIBRATED BANDPASS SHAPE – COMPARISON BETWEEN DIFFEREN SWEPT

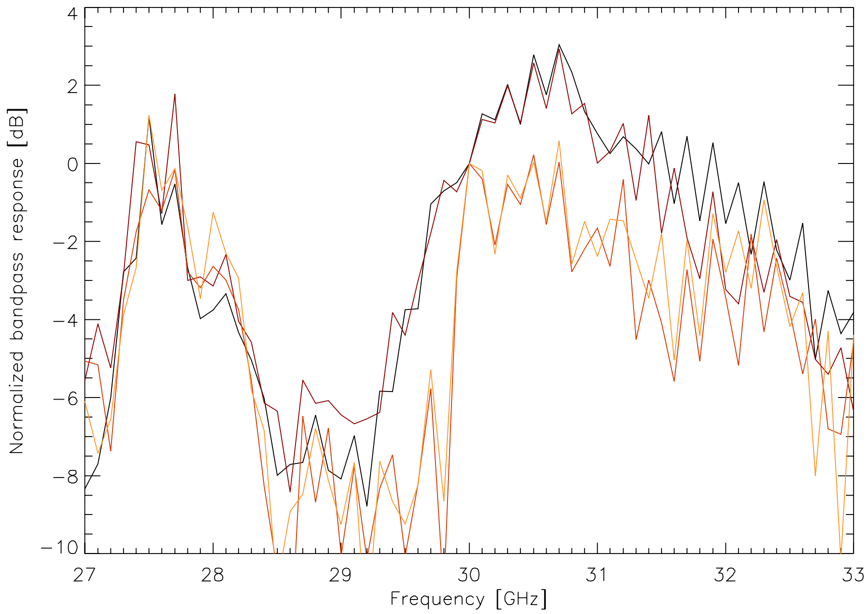


FIGURE 19: COMPARISON OF THE CALIBRATED BANDPASS SHAPE OF THE FOUR DETECTORS –DET 1 IS BLACK; DET 2 IS BROWN; DET 3 IS RED, AND DET 4 IS ORANGE.

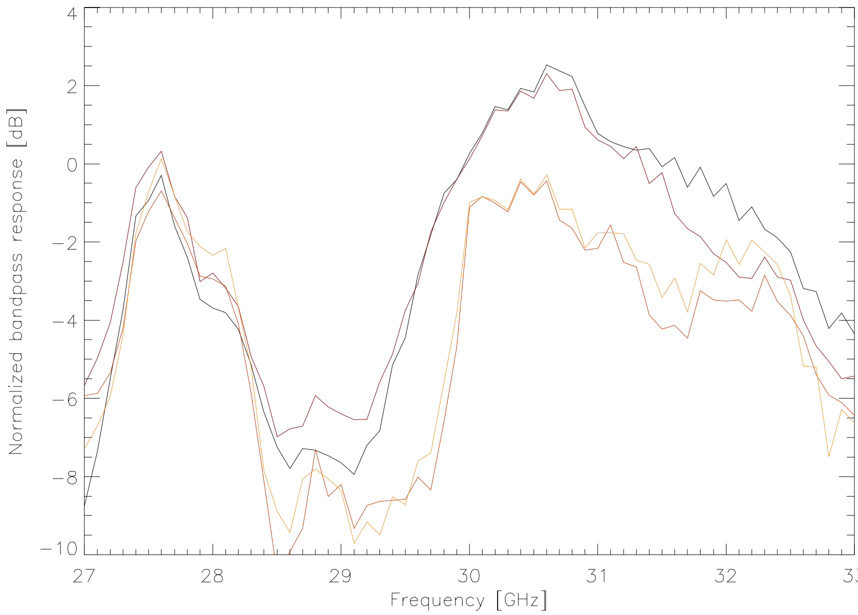


FIGURE 20: COMPARISON OF THE CALIBRATED BANDPASS SHAPE OF THE FOUR DETECTORS. DATA HAVE BEEN BINNED WITH A BINNING OF 2 POINTS. –DET 1 IS BLACK; DET 2 IS BROWN; DET 3 IS RED, AND DET 4 IS ORANGE.

7 ACKNOWLEDGEMENTS

I wish to thanks FRACARRO Radioindustrie S.p.A (http://www.fracarro.com) for having provided the sweep generator, and accessories for six months during the QM campaign.

FRACARRO Radioindustrie S.p.A will provide also the instrument during the Flight Model Test Campaign under a Letter of Agreement signed with IASF–Bologna.

8 ANNEX 1

A note on Swept Source Data Analysis

Fabrizio Villa

Measurement Concept

The outupt voltage of a typical LFI-like pseudo correlation radiometer is

$$\begin{aligned} V &= \frac{1}{\Delta\nu}\int_{\Delta\nu} S(\nu)\cdot[(T_{sky}+T_{noise})-r\cdot(T_{ref}+T_{noise})]\cdot d\nu = \\ &= \overline{S}\cdot[(T_{sky}+T_{noise})-r\cdot(T_{ref}+T_{noise})] \end{aligned} \quad (1)$$

where $S(\nu)$ is the frequency dependent radiometer sensitivity (V/K), T_{sky} is the antenna temperature at the sky horn, T_{ref} is the antenna temperature at the reference horn, and r is the gain modulation factor. For a DC balanced radiometer ($V_{out}=0$), the modulation factor is defined as follows:

$$r = \frac{T_{sky}+T_{noise}}{T_{ref}+T_{noise}} \quad (2)$$

T_{sky}, T_{ref}, and T_{noise} are antenna temperature of broadband signals. A nearly perfect monocromathic signal can be seen as a broadband brighness temperature multiplied by a narrow-band function as $T_{spt}(\nu)=T_{spt}\delta_{\nu}$. When such a signal is injected into the radiometer the output is

$$\begin{aligned} V_{\nu} &= \frac{1}{\Delta\nu}\int_{\Delta\nu} S(\nu)\cdot[T_{spt}(\nu)+(T_{sky}+T_{noise})-r\cdot(T_{ref}+T_{noise})]\cdot d\nu \\ &= S(\nu)\cdot T_{spt}+\overline{S}\cdot[(T_{sky}+T_{noise})-r\cdot(T_{ref}+T_{noise})] \end{aligned} \quad (3)$$

differencing the equations 7 and 1 we obtain

$$V_{\nu}-V = S(\nu)\cdot T_{spt} \quad (4)$$

From a general point of view, the equation above can be rewritten in the following way, considering a general output offset level, $\mathcal{O}$, and losses, $\mathcal{L}$, of the transmission line carrying the signal from the sweeper to the sky horn:

$$V_{\nu} = S(\nu)\cdot T_{spt}\cdot\mathcal{L}+\mathcal{O} \quad (5)$$

1

2

The band response of the radiometer is calculated

$$S(\nu) = \frac{(V_\nu - \mathcal{O})}{T_{spt} \cdot \mathcal{L}} \quad (6)$$

Radiometer band measurement shall be performed by injecting a monocromathic signal into the sky horn and record the output voltage. As the signal swept in frequency the output voltage will change according to equation 6 No absolute value of the radiometer sensitivity is required (this shall be derived from other tests). Only relative variation is required to be know. This means that the knowledge of the absolute value of the input signal is not required. The main problem is the knowledge of the offset. Here, we describe two methods describing the offset calculation.

Method 1: Offset calculation from very off–band response

Very off-band radiometer sensitivity is zero. Assuming $r = 1$, and $S(\nu^\star) = 0$ at frequency $\nu^\star$, from equation 7 we have

$$V_{\nu^\star} = \overline{S} \cdot [(T_{sky} + T_{noise}) - (T_{ref} + T_{noise})] = \mathcal{O} \quad (7)$$

Method 2 from RaNA r factor calculation

If the modulation factor r is calculated as in Equation 2 with the sweep generator off, the offset is the data is zero.

$$\begin{aligned} V_\nu &= S(\nu) \cdot T_{spt} + \overline{S} \cdot [(T_{sky} + T_{noise}) - r \cdot (T_{ref} + T_{noise})] \quad (8) \\ &= S(\nu) \cdot T_{spt} \end{aligned}$$

The modulation factor can be calculated from RaNA software on the data taken with the sweeper off and immediately befor the swept test.