BRAND Front-end Cryogenic Noise Measurements at Yebes. Polarization #2.

BRAND/Yeb-TR-2019-003
IT-CDT-2019-22

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Date: 2019-12-02

Revision: A

Confidential: For internal use only

Change Record

Revision	Date	Affected Paragraphs(s)	Reason/Initiation/Remarks
A	2019-12-02	All	First Issue

Outline

1. Introduction

This report is continuation of BRAND/Yeb-TR-2019-002 [1] about the measurements of the front-end components of one polarization branch of the BRAND-EVN receiver. This report presents the results of the other branch obtained at Yebes Observatory labs.

Refer to section 3 of [1] for details about the measurement procedures and the measurement setups used. Note that in this measurement campaign, the complete chain with coupler was not measured, but only the highpass and notches filters. As concluded from the manufacturer data and [1], the superconducting coupler has a design flaw which makes it unusable above 11 GHz. A new design is expected.

The characterization of the loss of each superconducting filter is made by measuring its noise contribution at the input of the LNA. Both are also cascaded together with the balanced amplifier. A justification of this approach and some background information about the project can be found in section 1 of [1].

2. Superconducting filters data

We include here as a reference the information received from the manufacturer of the coupler and the filters. Only the data corresponding to the units used is presented.

The serial number of the units measured is 190-4A01[1].

The highpass filter specified cutoff frequency is 1.5 GHz.

The rejection frequencies for the notch filter as specified in [4] are 1.83-1.86 GHz and 2.11-2.17 GHz. The manufacturer measures rejection >23 dB @ (1.836, 1.854) and >18 dB @ (2.118, 2.169).

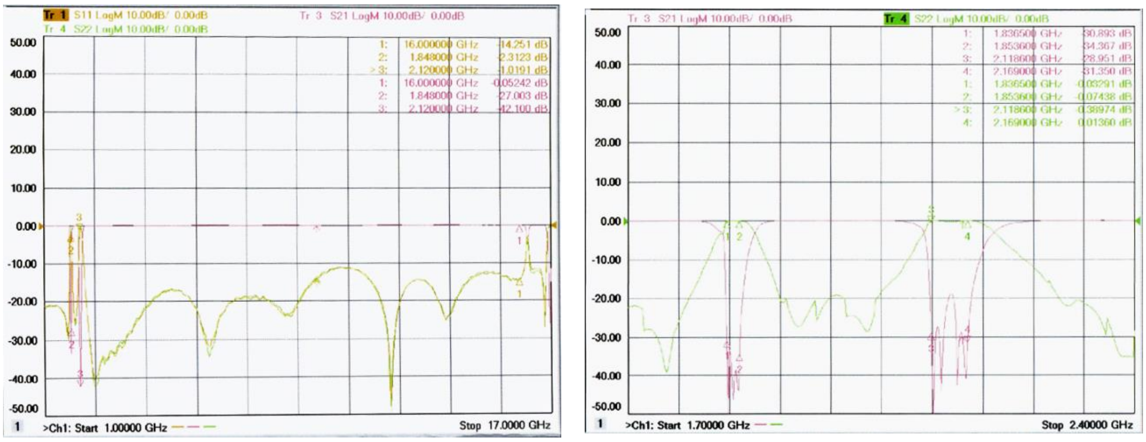

Figure 1: *Notch filter response data measured by the manufacturer.*

[1] Surprisingly, there is a common serial number for all units. The different units can be distinguished by the labels Notch Filter, Highpass Filter, Coupler. There is another set for the other polarization with serial number 190-4A02

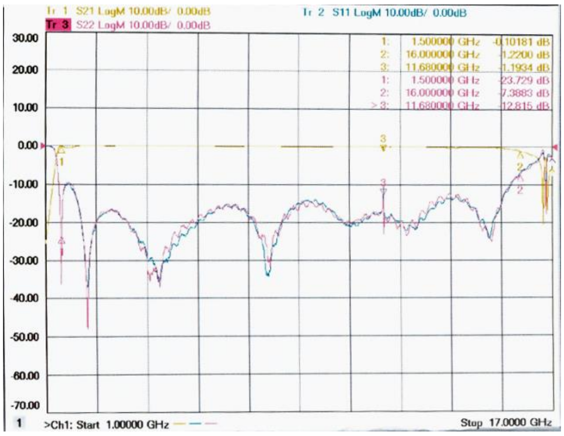

Figure 2: *Highpass filter response data measured by the manufacturer.*

3. Measurements

We have reproduced the exactly same procedures and setups of the first batch of measurements for the other polarization branch, as described in [1], to ensure that the results are comparable.

Follows a list of the different setups measured. Photographs of the each one are shown in the next section.

1. Reference measurement of the balanced LNA
2. Notch filter: Notch filter + LNA
3. Highpass filter: Highpass filter + LNA
4. Complete chain excluding the Coupler: Highpass filter + Notch filter + U-cable + LNA
5. Verification measurement of the balanced LNA

We have used the **balanced amplifier** with LNAs Y214G 1016 and 1018 and hybrids YH90214 3022 and 3024. All measurements have been obtained with the LNAs in the nominal operating conditions stated in [2]. The bias settings are shown in table 1.

LNAs Bias Settings

Stage	#1	#2	#3
Drain Voltage (V)	2.8	1.2	3.0
Drain current (mA)	12	5	15
Gate Voltage (V)	0.04	-0.11	-0.11

Table 1: *Bias settings of both amplifiers used in all the measurements presented.*

4. Results

Table 2 reflects the temperature of the different components of each measurement setup.

SENSOR TEMPERATURE IN K (LNA ON)

Setup	#1	#2	#3	#4	#5
50 K plate ref.	59.81	60.84	60.70	61.74	60.22
12 K plate ref.	16.53	17.12	17.07	17.05	16.55
Cold attenuator	16.10	16.45	16.37	16.87	16.16
LNA	15.58	16.02	15.88	15.77	15.57
Input hybrid	12.00	12.18	12.09	12.26	11.96
Notch filter	-	14.43	14.23	14.31	-
Highpass filter	-	-	-	14.17	-

Table 2: *Readings of the temperature sensors used in the different setups.*

For each measurement configuration we present a graph comparing the noise and gain of the set measured with the noise and gain of the balanced LNA with a frequency resolution of 200 MHz. Details of some plots were measured with finer resolution (50 MHz or 20 MHz) and displayed independently.

Another plot represents the loss of the DUT in two curves, one calculated from the noise increment due to the DUT and another, less accurate, subtracting the gain of the LNA and the gain of the set, resulting from the Y factor measurements. A linear fit to the loss curve derived from the noise measurements is also presented in the plot.

The average value in the band of the loss for each DUT is presented in the following table. These values do not represent the superconducting losses only, as they include ripples in the response of the DUTs, transitions, connectors and the "U" cable, depending on the setup.

	ΔT_{eq} ($T_{eq\ DUT+LNA} - T_{eq\ LNA}$)	L (from ΔT_{eq})	L (from ΔG)
Highpass filter	1.14	**-0.20**	(0.20)
Notch filter	0.80	**-0.14**	(0.09)
Highpass+Notch filters	2.58	**-0.45**	(0.40)

Table 3: Average loss in the band for the *different setups estimated from noise measurements with the LNA and from gain difference (less accurate, between brackets).*

4.1.Setup #1: Amplifier reference measurement

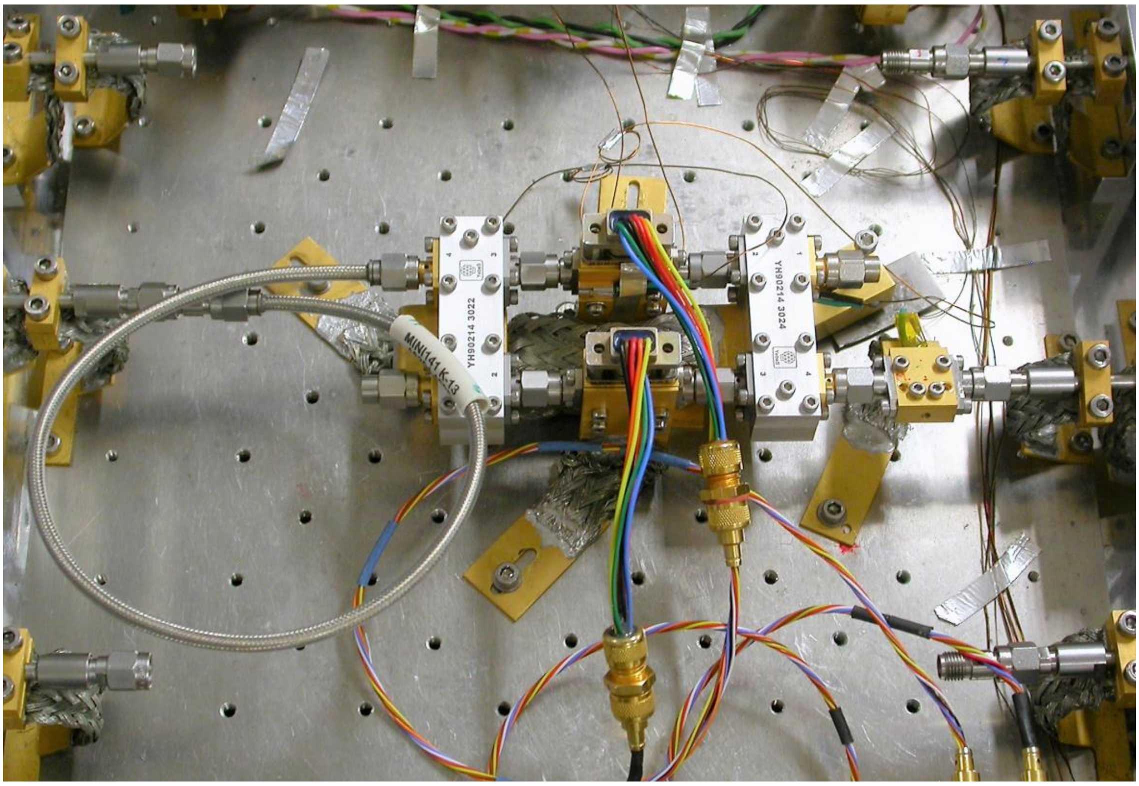

Figure 3: *Setup 1&5 – Balanced amplifier reference measurement. Input and cold attenuator are on the right.*

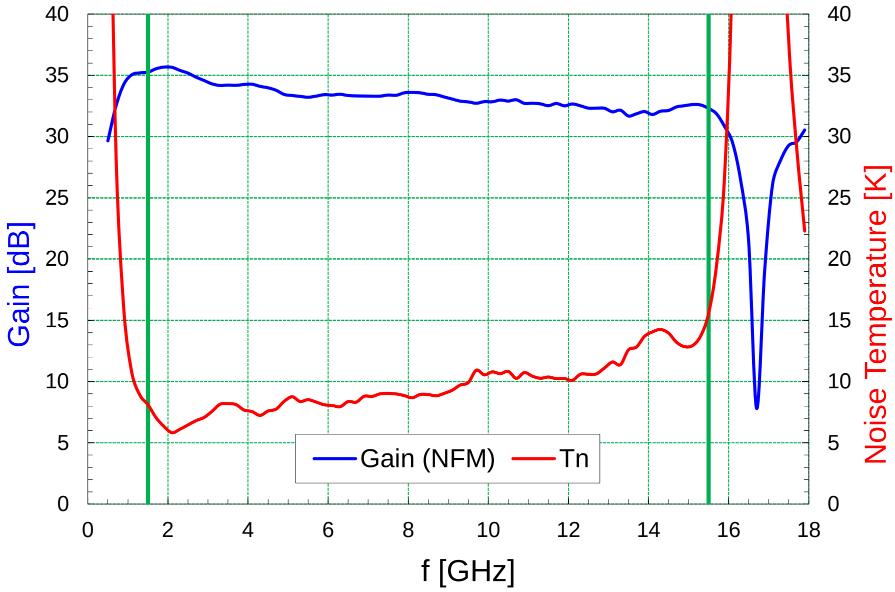

Figure 4: *Balanced amplifier noise and gain reference measurement The noise measurements taken at the beginning and end of the campaign differ on average in 0.1 K.*

4.2.Setup #2: Highpass filter + LNA

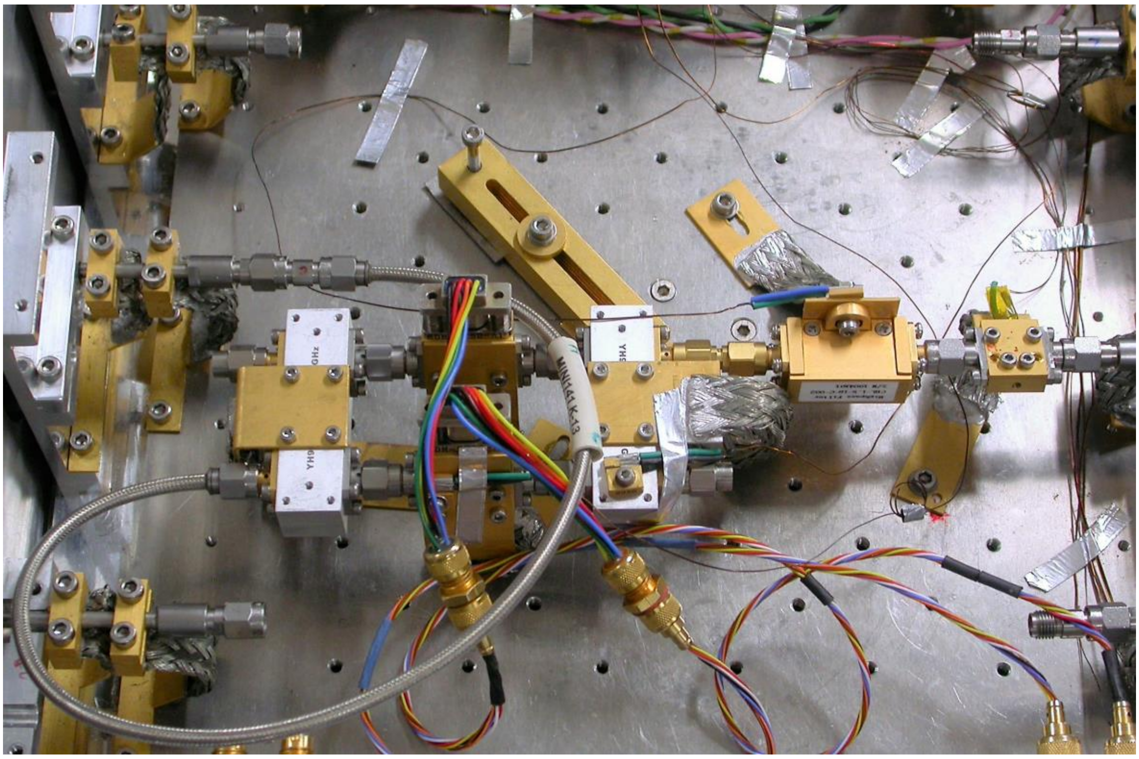

Figure 5: *Setup 2 – Highpass filter + Balanced amplifier. Input and cold attenuator are on the right. The male to male SMA transition is included in the results.*

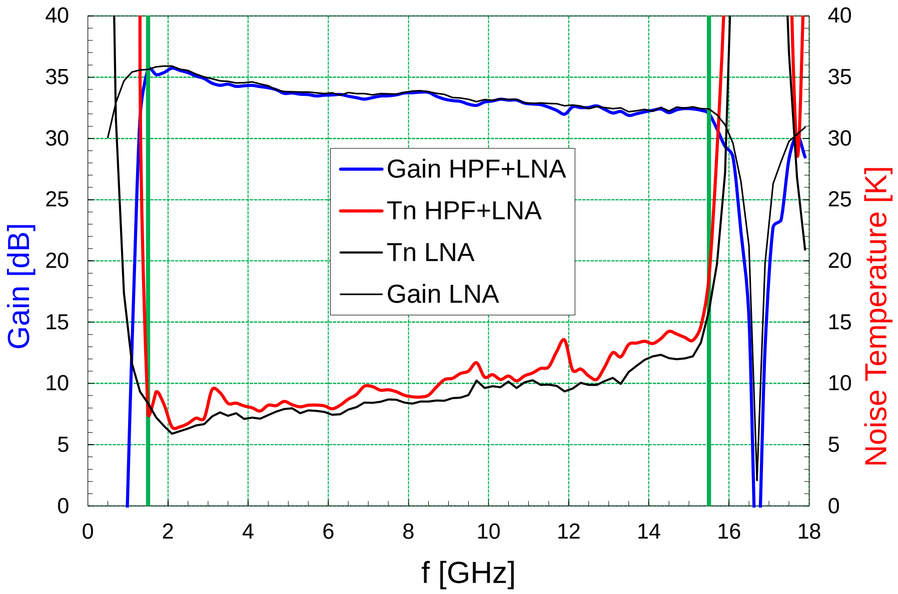

Figure 6: *Highpass filter + Balanced amplifier noise and gain compared to balanced amplifier alone. Several noise bumps due to the irregular response of the highpass filter can be noticed. Some of them are zoomed in the following figures.*

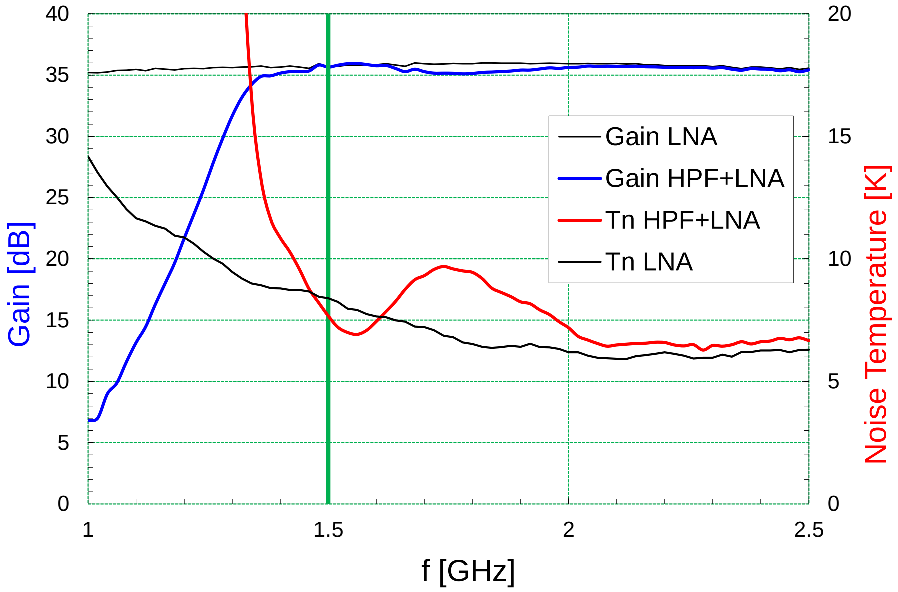

Figure 7: *Detail from the previous figure of the high noise contribution of the highpass filter between 1.5 and 2 GHz due to the ripple of its transfer function close to the cutoff frequency.*

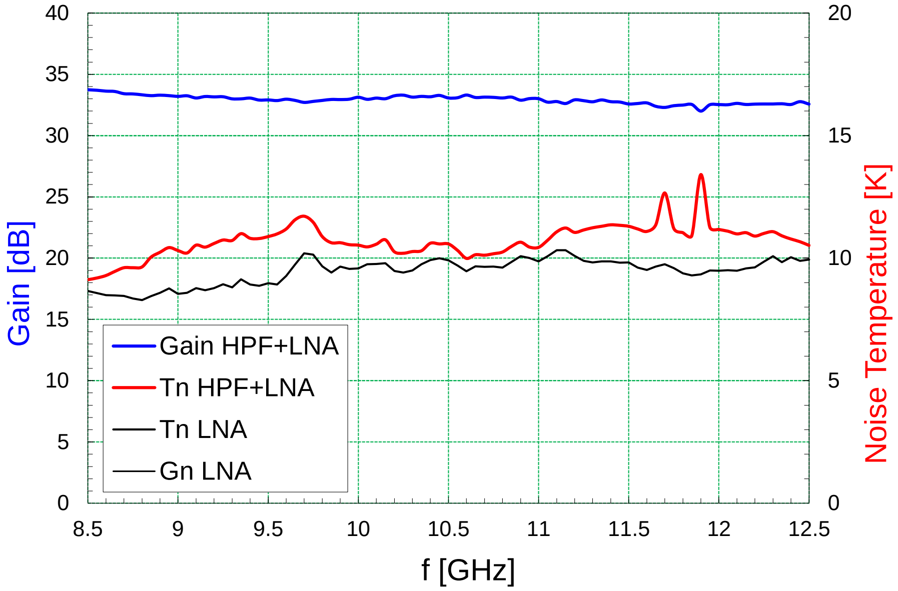

Figure 8: *Detail of a noise bump produced by the poor passband response of the highpass filter. One of the noise spikes around 11.7 GHz, probably due to some resonance, is clearly shown in the filter response of figure 2.*

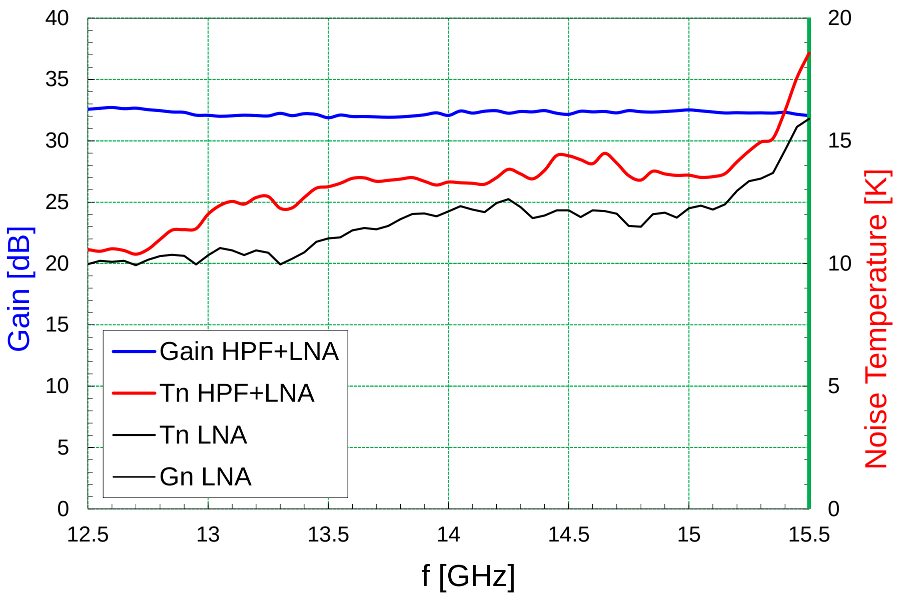

Figure 9: *Detail of the noise degradation at the higher end of the band produced by the poor passband response of the highpass filter.*

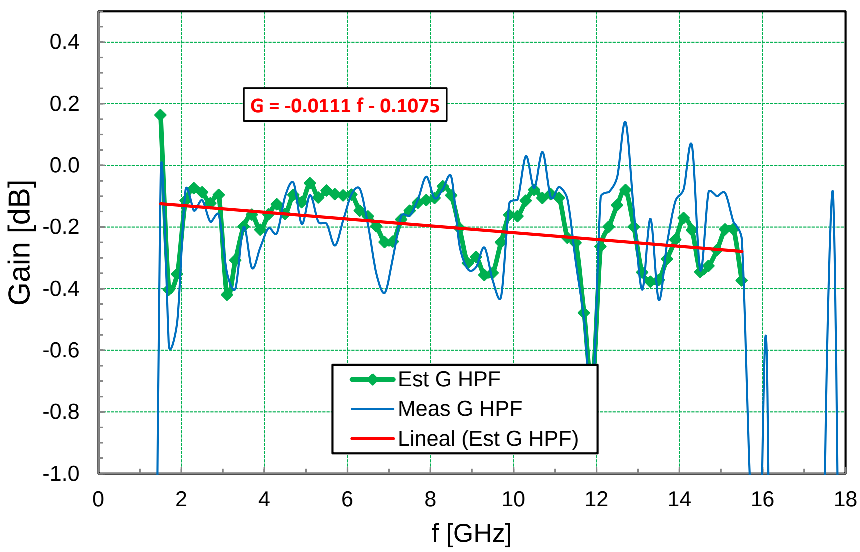

Figure 10: *Highpass filter loss. In green, the estimation from noise measurements. In red, the linear fit of the green curve. In blue, a direct loss calculation from the gain obtained in the noise measurement. Average loss in the band from noise measurements is* ***0.20 dB****.*

4.3.Setup #3: Notch filter + LNA

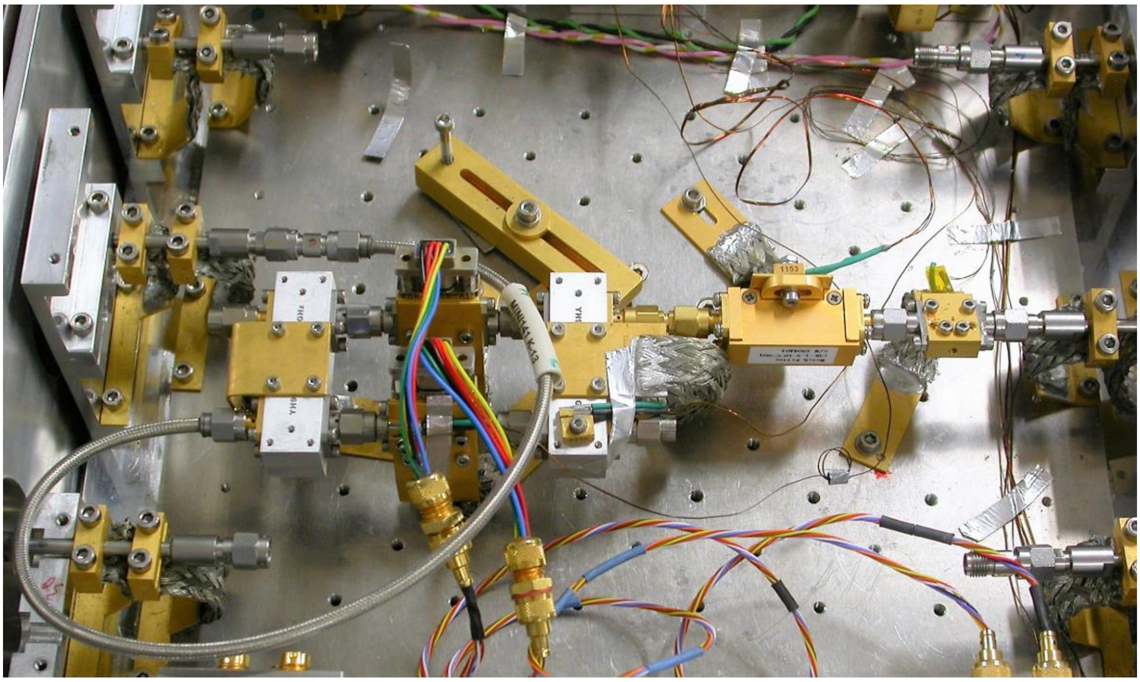

Figure 11: *Setup 3 – Notch filter + Balanced amplifier. Input and cold attenuator are on the right. The male to male SMA transition is included in the results.*

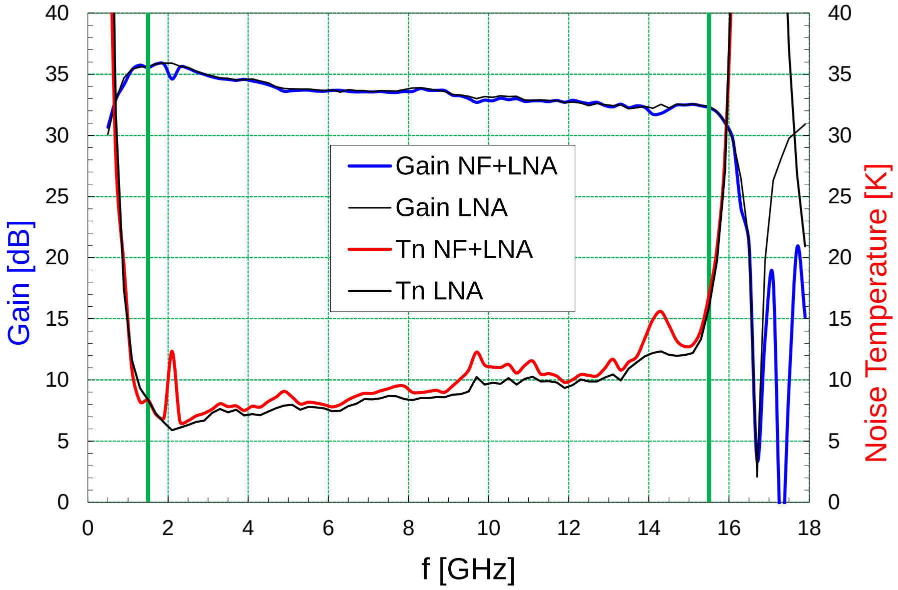

Figure 12: *Notch filter + Balanced amplifier noise and gain compared to balanced amplifier alone. Some of the bumps in noise temperature produced by the irregular response of the notch filter are zoomed in the following figures. The notches are not well resolved with this frequency sampling; the next figure shows both.*

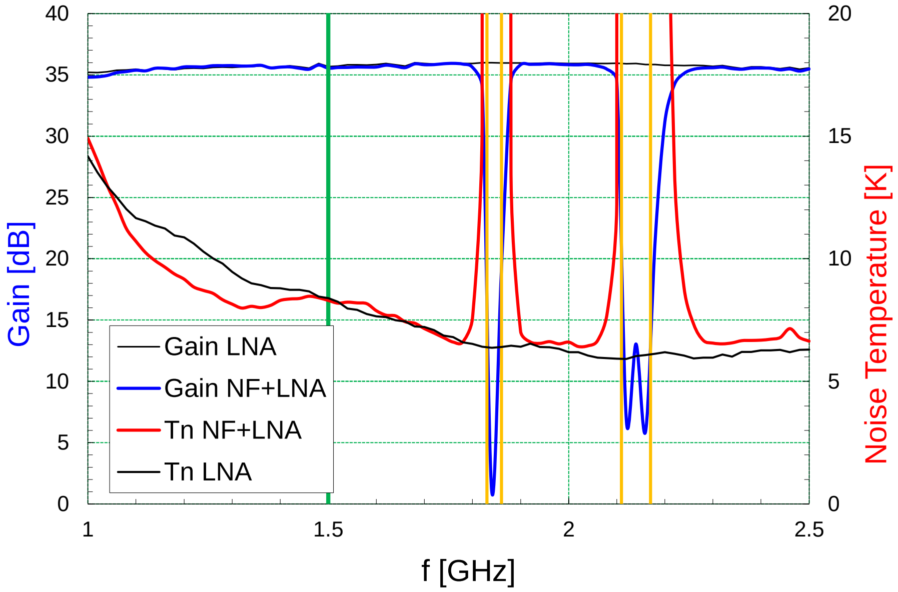

Figure 13: *Detail of the notches from the previous figure. Vertical orange lines signal the specified notch stopbands. Note how the band really affected by the noise degradation is twice as wide as the notch.*

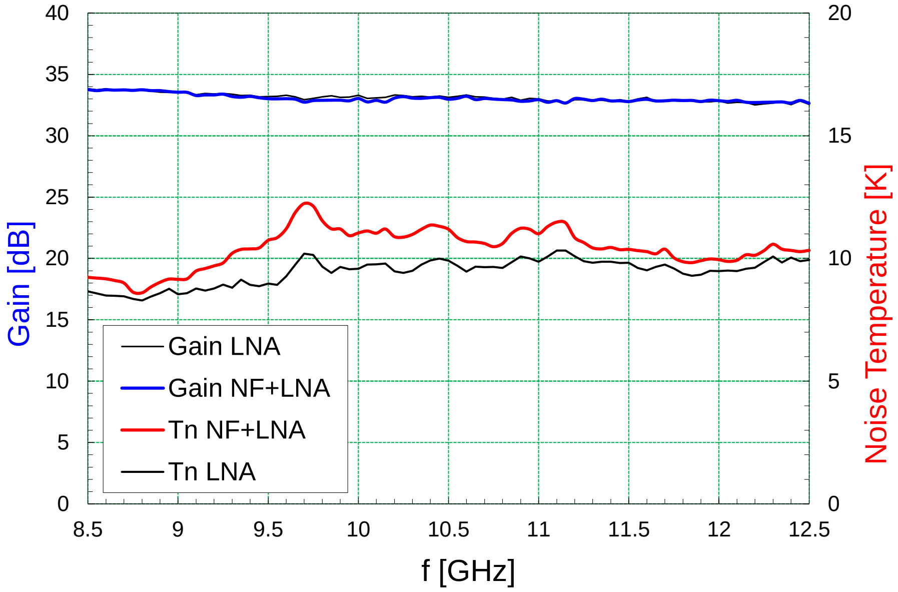

Figure 14: *Detail of a noise bump produced by the poor passband response of the notch filter.*

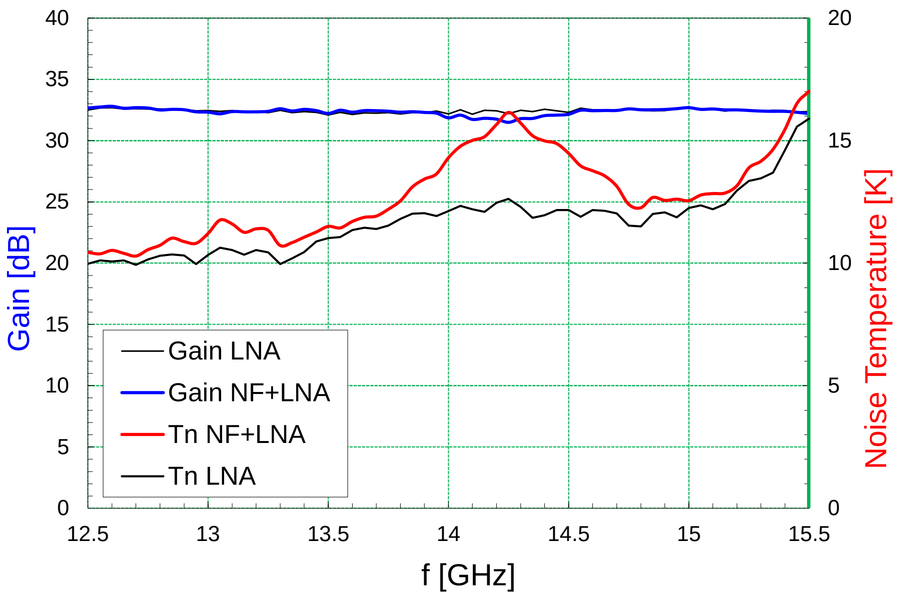

Figure 15: *Detail of a noise bump produced by the poor passband response of the notch filter.*

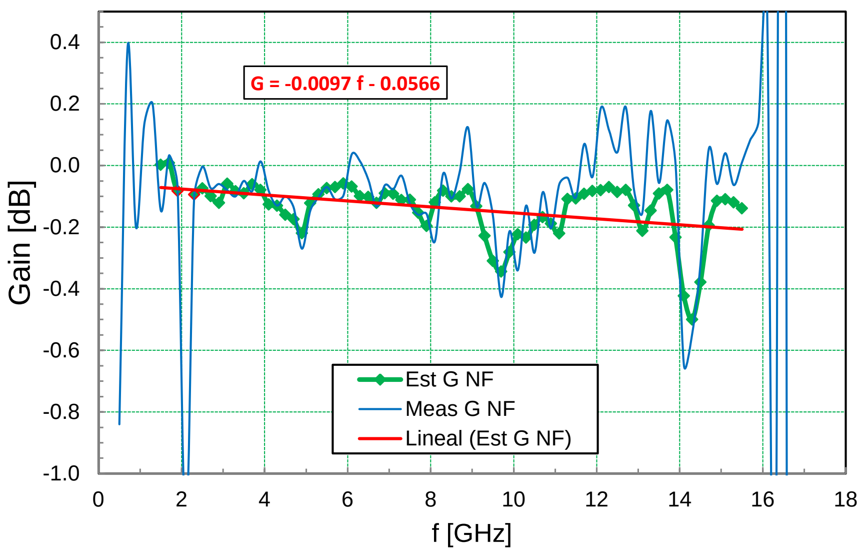

Figure 16: *Notch filter loss. In green the estimation from noise measurements. In red, the linear fit of the green curve. In blue a direct loss calculation from the gain obtained in the noise measurement. Average loss in the band from noise measurements is* ***0.14 dB****. The notch frequencies have been eliminated from the linear regression and average calculation.*

4.4.Setup #4: Highpass filter + Notch filter + LNA

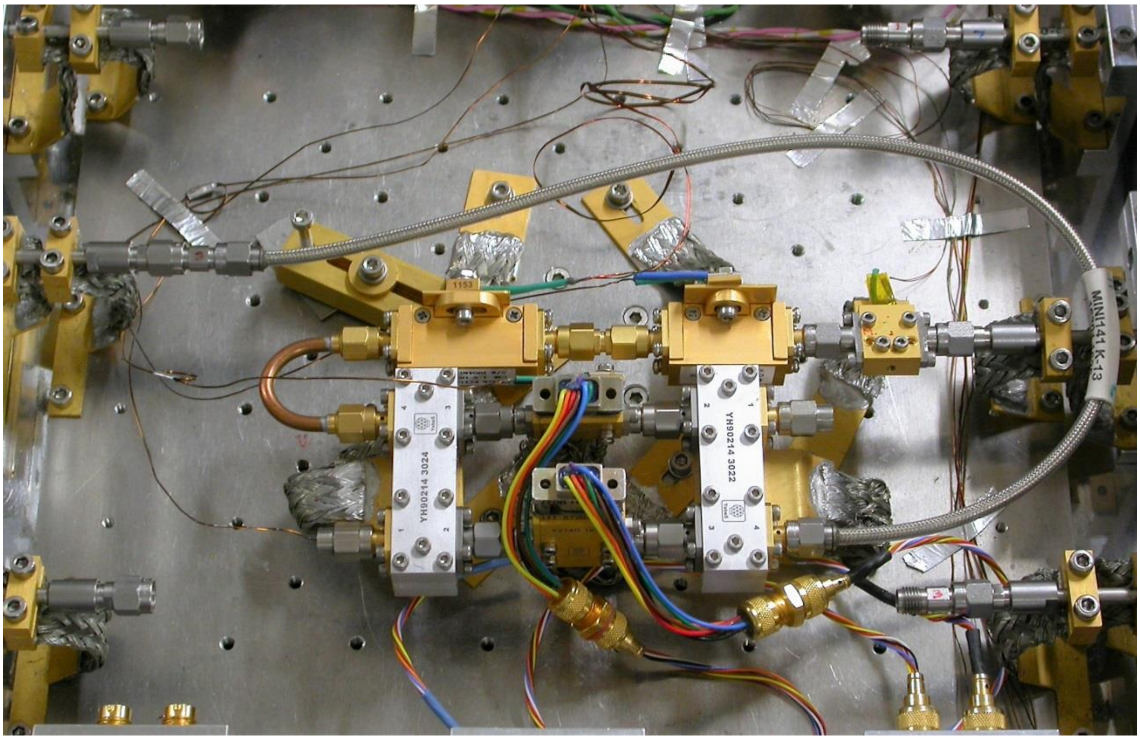

Figure 17: *Setup 4 – Highpass filter + Notch filter + "U" cable + Balanced amplifier. Input and cold attenuator are on the right. The male to male SMA transition is included in the results.*

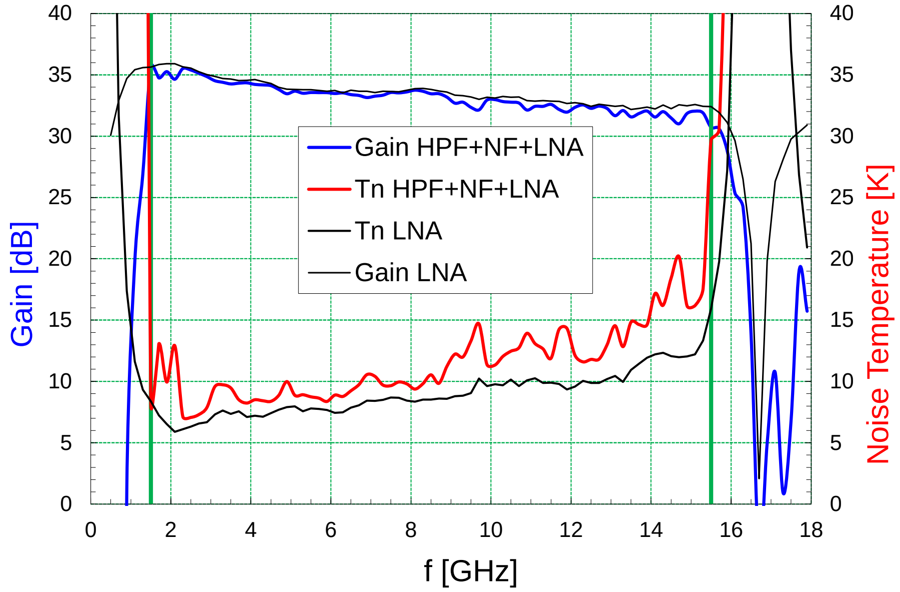

Figure 18: *Highpass filter + Notch filter + "U" cable + Balanced amplifier noise and gain compared to balanced amplifier alone. Note the various features introduced by combined effect of the filters and the reflections between the different components, some of them zoomed in the next figures.*

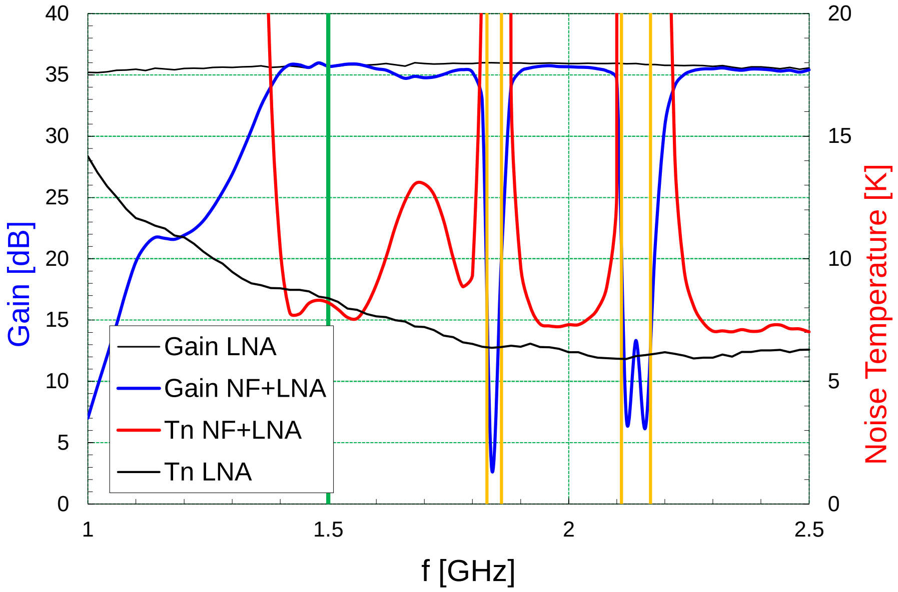

Figure 19: *Detail of the lower end of the band, contaminated by the notches and the ripple of the highpass filter.*

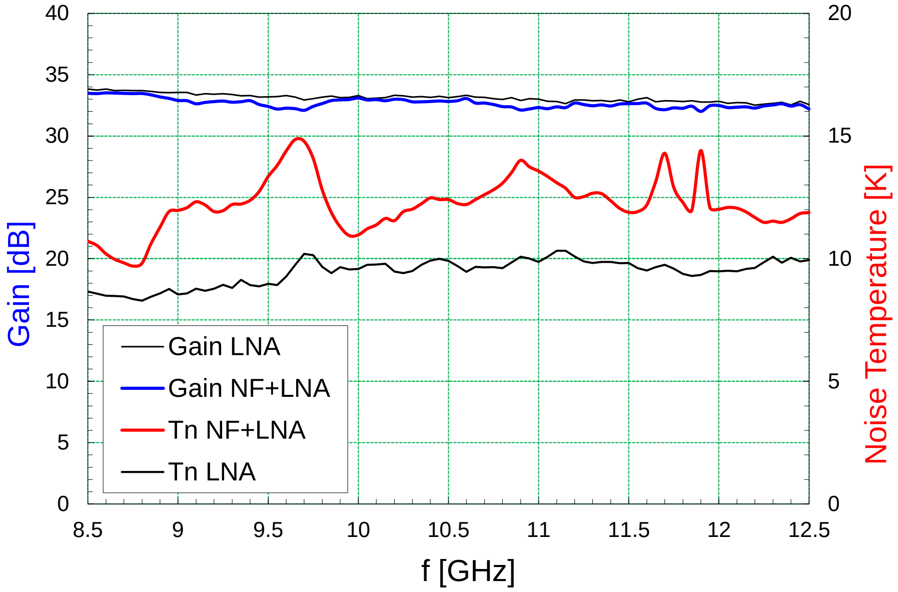

Figure 20: *Detail of the band of figures 8 and 14, showing noise bumps from both filters and the spikes due to the highpass filter.*

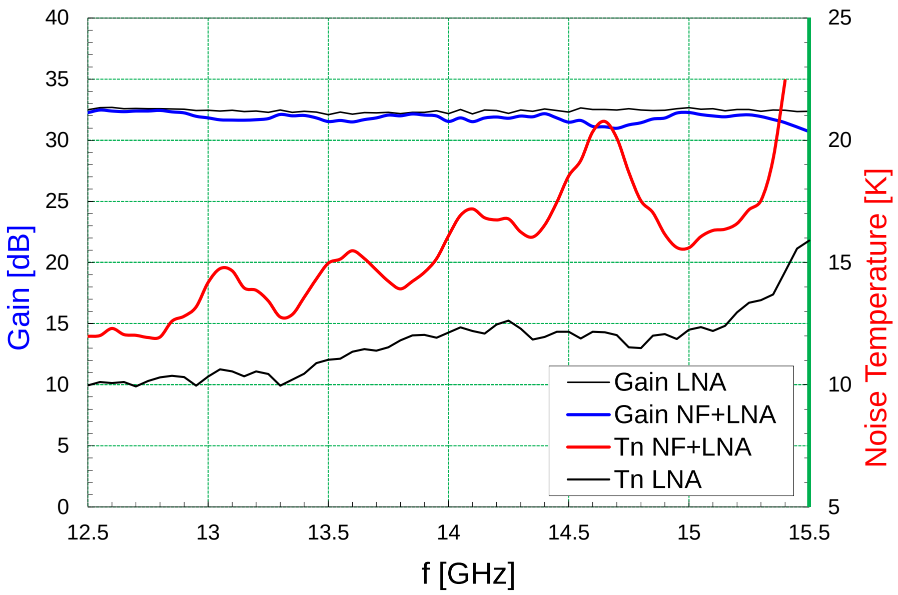

Figure 21: *Detail of the band of figures 9 and 15, showing noise bumps and ripples from both filters and a the reflections between components.*

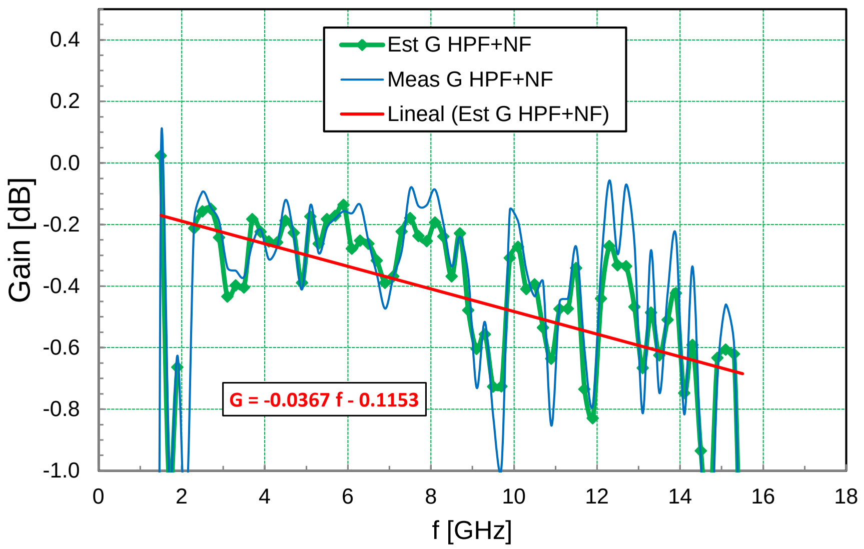

Figure 22: *Highpass filter + Notch filter + "U" cable loss. In green, the estimation from noise measurement (notches are excluded). In red, the linear fit of the green curve. In blue, a direct loss calculation from the gain obtained in the noise measurement. Average loss in the band from noise measurements (without notches) is* ***0.45 dB****.*

5. Conclusions

- The complete chain of filters and balanced amplifier has been successfully measured at 15 K. No major new problems were detected in the assembled receiver chain. Despite the use of the "U" cable and the non-ideal reflection coefficient of some of the components, the noise ripples are quite low and significant comparisons between the amplifier noise and the noise with the different components at the input could be made.

- The results are coherent. The losses of the superconducting elements are very low, taking into account the SMA connectors and transitions included in the measurements: around 0.15-0.20 dB for each filter module plus male to male transition. It is possible to check that the sum of the loss of the two filters measured individually (0.14+0.20=0.34 dB) minus the loss of the two filters measured together (0.45 dB) is 0.11 dB, which accounts for cryogenic losses of the miniature “U” cable minus the extra male to male adapter used in the joint measurement and the measurement uncertainties.
- The repeatability of the measurements is very good (0.1 K average difference between the LNA measurements at the beginning and end of the campaign) and the stability of the measurement system and the temperature of the LNA and DUTs in the different arrangements guarantees comparable results.
- The average noise increment due to the insertion of the filters in front of the balanced LNA is around 2.6 K (28% of the amplifier noise). The noise contribution is higher for higher frequencies (figure 18).
- The highpass filter response shows the same ripple in the band near the cutoff frequency (1.55-2 GHz) reported in [1] (see figure 7). However, the noise bumps and specially the degradation at the high end of the band (figure 9) are worse in this unit than in the one tested in [1]. A resonance around 11.7 GHz is clearly seen in the noise plot (figure 8).
- The stop bands of the notch filter affect a band clearly wider than the specification (see figure 13). The flank of the higher cutoff frequency of each notch is less steep. As a result, the notch specified between 2.11 and 2.17 GHz has a noise passband of 2.09 and 2.23 (for a 50% increment of noise temperature). The main bumps reported in [1] for this filter (figures 14 and 15) are similar (higher the 9-11 GHz and lower the 14-14.5 GHz).

References

[1] Isaac López-Fernández, Ricardo Amils, Juan Daniel Gallego, Carmen Diez, Inmaculada Malo, "*BRAND Front-end Cryogenic Noise Measurements at Yebes. Polarization #1*", BRAND/Yeb-TR-2019-002 rev. B (IT-CDT-2019-8).

[2] Isaac López-Fernández, Inmaculada Malo, Carmen Diez González, Juan Daniel Gallego Puyol, "*1.5-15.5 GHz cryogenic low noise balanced amplifier report. Units: Y214G1014-15+YH903023-21 and Y214G1016-18+YH903024-22*", BRAND/Yeb-TR-2019-001 (IT-CDT-2019-5).

Appendix: S-parameter measurements

Figure 23 shows the S parameters of the different arrangements measured in the noise setup with the cryogenic attenuator at the input. A time domain gating has been applied to S11 and S22 to reduce the gain and phase variations at the input attenuator, stainless steel lines and flexible cable when cooled down. However, the results still present ripples; they are useful mainly to detect issues and compare setups.

Better measurements of the return loss of the LNA alone (without the effect of the input attenuator) are available in [2].

(a) (b) (c) (d)

Figure 23: *S parameters measured with noise attenuator at the input of (a) Balanced LNA (b) Notch filter + LNA (c) Highpass filter + LNA (d) Highpass filter + Notch filter + U-cable + LNA.*