Improved Design of a Q band (33-50 GHz) Cryogenic Heated Load in Waveguide for Precision Noise Measurements with Reduced Heat Capacity.

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1. Introduction.

A heated load is an alternative to hot/cold loads method because it improves accuracy, reduces the ripple of the measurements and eliminates the need of liquid nitrogen. In the Technical Report CDT 2016-3 we presented the results of a heated load designed for the Q band and concluded that the cooling speed should be improved in order to obtain a more practical and convenient method of measurement.

The cooling speed can be enhanced by reducing the heat capacity of the load. This requires a totally different mechanical design. This report presents a reduced mass alternative design which improves the cooling speed by almost three times. Following the structure of CDT 2016-3, this report presents the results of the measurements with the new heated load, referred as version 2 (v2), for comparison with the previous design (referred as v1).

2. Fabrication of the new waveguide heated load.

The new heated load is built with a piece of regular rectangular WR-22 cooper (Cu) waveguide with the absorber inside. The elimination of the aluminum split block drastically reduces the mass of the load. The stainless steel waveguide[1] is directly soldered[2] to the cooper waveguide eliminating the two flanges, further reducing the total mass. The absorber material and shape is the same of the previous version (v1). The absorber piece is inserted into the Cu waveguide by the free end. Probably only part of the piece of absorber is perfectly glued to the waveguide walls since the epoxy[3] initially deposited in two of the sides of the absorber is dragged when the piece is inserted. Due to this, the thermal contact between the absorber and the waveguide could be worst than in the previus version. The 50 Ω heater is made of a nichrome wire[4] rolled around the Cu waveguide and covered with non-conductive epoxy[5] for protection. The temperature sensor is attached to the Cu waveguide by means of a small copper plate[6] soldered with indium[7].

3. Thermal performance.

The PID parameters are estimated by the "Autotuning" function of the 336 Temperature Controller with a physical temperature of the load of 40 K. The configuration used for the

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[1] *50 mm in length (the same used in heated load v1).*
[2] *SnPb alloy: SN60; fusion temperature: 190 ºC.*
[3] *Epoxy Scotch-Weld EC2216.*
[4] *NiCr wire, AWG 32, Lakeshore WNC-32-250. For 50 Ω a length of 1.50 m is needed.*
[5] Epoxy Scotch-Weld EC2216
[6] *Cu 1 mm thick.*
[7] *Indium alloy (paste): 97IN3AG; fusion temperature: 143 ºC.*

noise measurements presented in this report included a ramp of 40 K/min. The base plate of the cryostat is stabilized to 15 K by an independent loop (output 2).

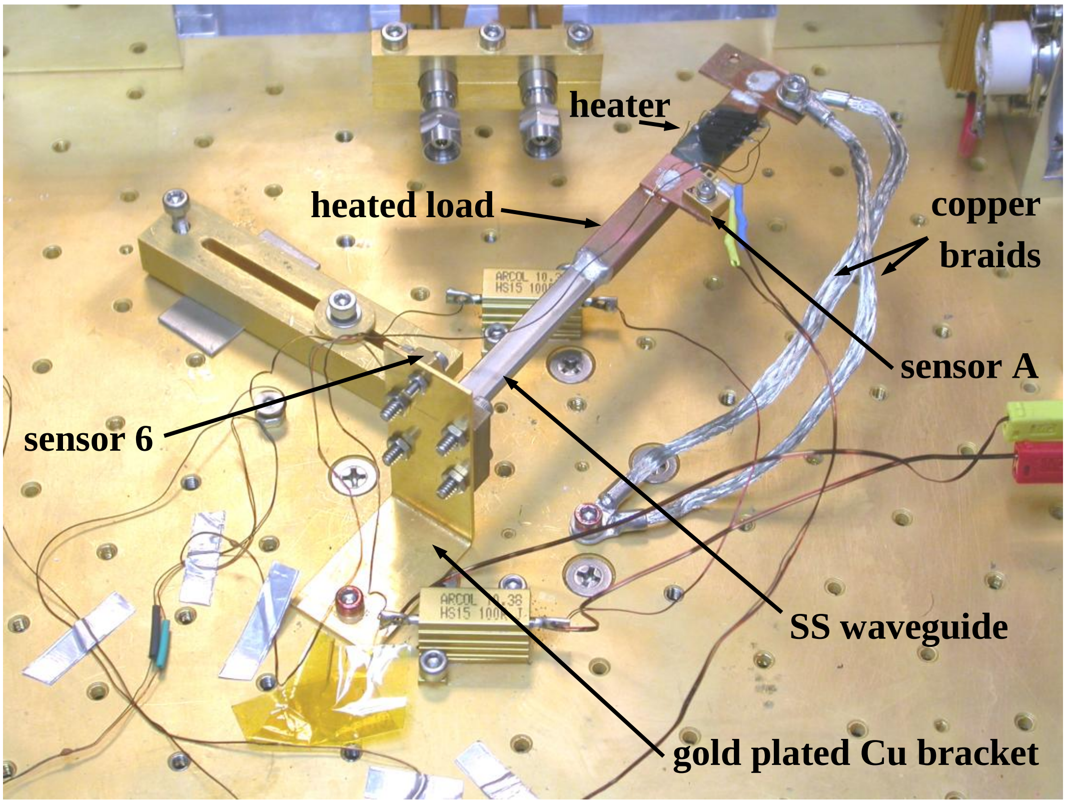

Figure 1. Setup for the heated load thermal test.

Table 1. Basic configuration parameters of the port "Output 1" of the 336 Temperature Controller used to connect it to the heater.

Parameter	*Data*
Heater resistance	50 Ω
Max. current	0.707 A
Input control	Sensor A
Mode	Closed loop PID
Ramp	40 $Kmin^{-1}$

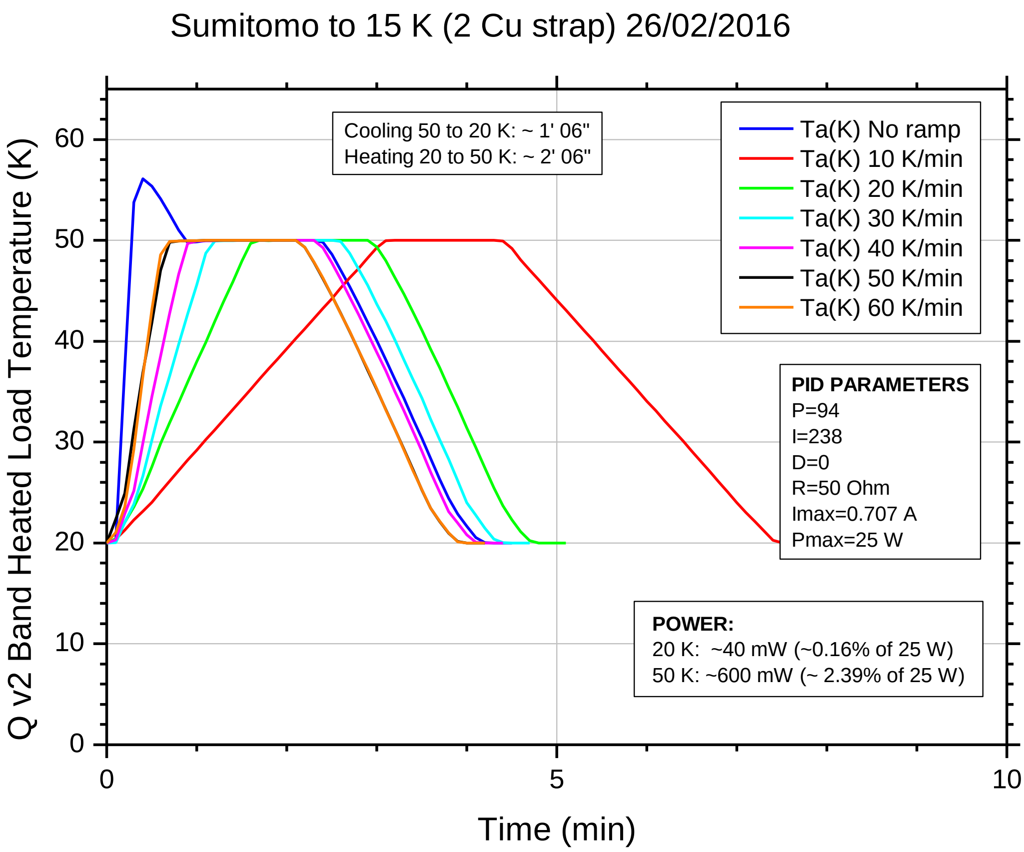

Figure 2. Thermal response of the Q band heated load v2 with two identical braids. A ramp of 50 K/min is the best option to minimize the heating time. The configuration used for the noise measurements presented in this report included a ramp of 40 K/min. An increase of 0.05 K was registered in the sensor attached to the L-shaped piece when the heated load set point was switched from 20 to 50 K.

4. Input reflection.

Input reflection of the new load (v2) is similar to the result obtained with the old load (v1) with the SS waveguide (see Figure 3).

5. Noise measurements.

The heated load was validated by performing cryogenic noise measurements of a Q band amplifier (YMQA 1006 4[8]) with waveguide input/output (square flange). The set-up is shown in Figure 4. It is interesting to note the reduction by half of the cooling time and the increase in the power required (almost double) to maintain the load at 50 K with respect to the thermal performance test described before. This is caused by a reduction by half of the thermal resistance of the load in this configuration. The cause is still unknown.

[8] *Test performed on YMQA 1006, a 35-50 GHz MMIC amplifier prototype for the ALMA project with WR22 waveguide ports (square flange). Cryogenic bias used: (0.6 8 0.28) (0.55 8 0.29) (0.8 16 0.28) (0.7 8 0.27).*

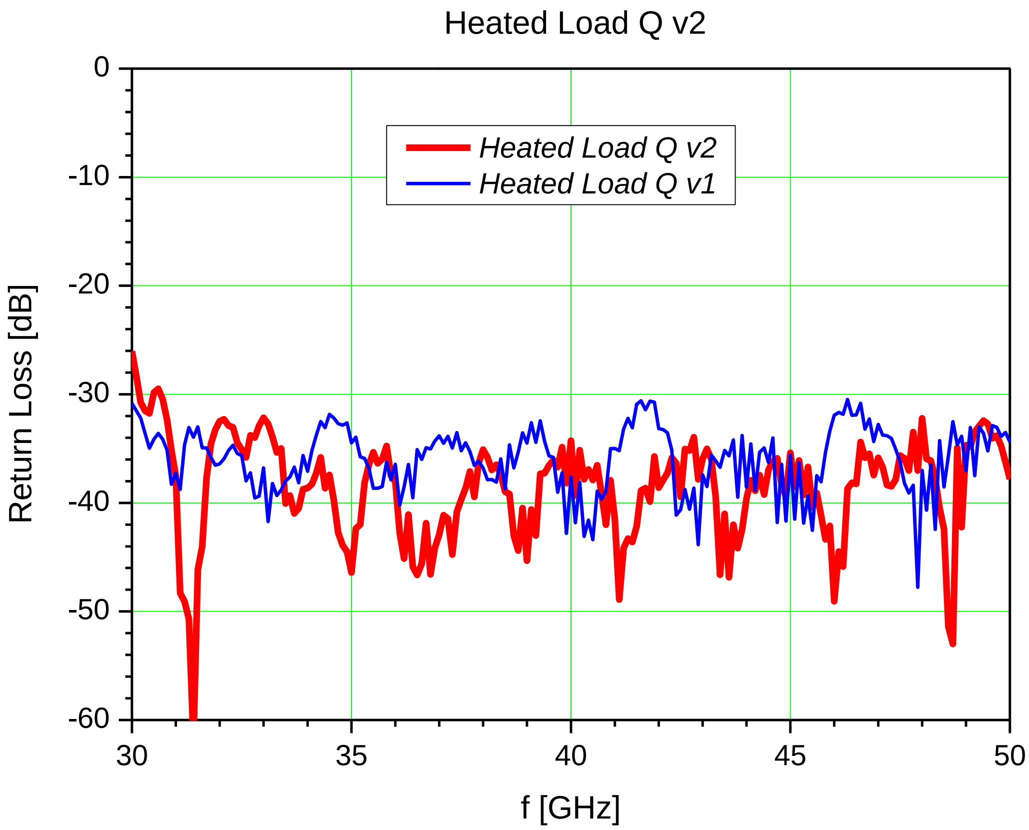

Figure 3. Return losses of the heated load in Q v2 band compared to the return losses of the heated load in Q band v1 with de SS waveguide.

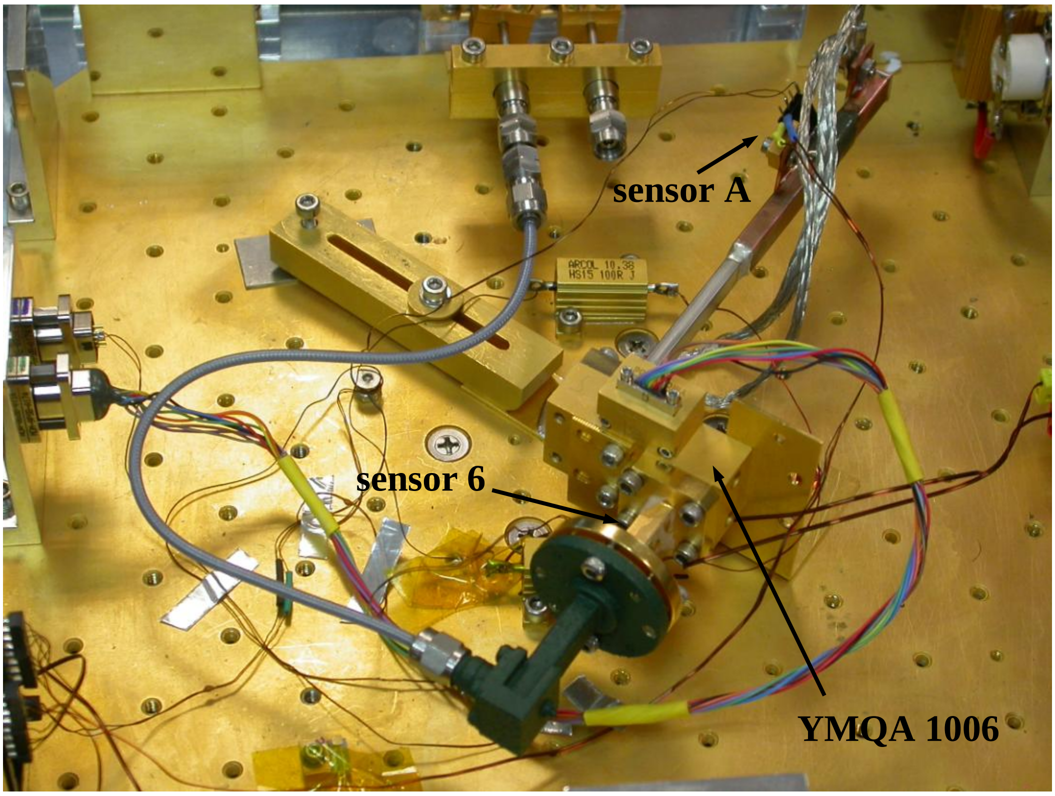

Figure 4. Measurement of the YMQA 1006 with the new Q heated load.

Comparison with LN2 and Q v1 heated load measurements

The results are compared with two previous noise measurements of the LNA, the one obtained using a short horn with ambient and LN2 absorbers and the measurement using the Q heated load v1. Table 2, Figure 5 and Figure 5 present the results of the comparison. The agreement between the measurements with the new (v2) and the old (v1) Q loads is almost perfect. The comparison of three consecutive independent measurements (not shown in this report) demonstrates the good repeatability of the measurements with the Q load v2.

Table 2. Comparison of the average noise temperature obtained in the 33-50 GHz band with ambient/LN2 absorbers and with the heated loads in Q band v1 and v2.

Measurement	*T mean (35-50 GHz)*
Horn: Ambient/ LN2 loads	18.28
Waveguide Heated load Q v1	17.17
Waveguide Heated load Q v2	17.27

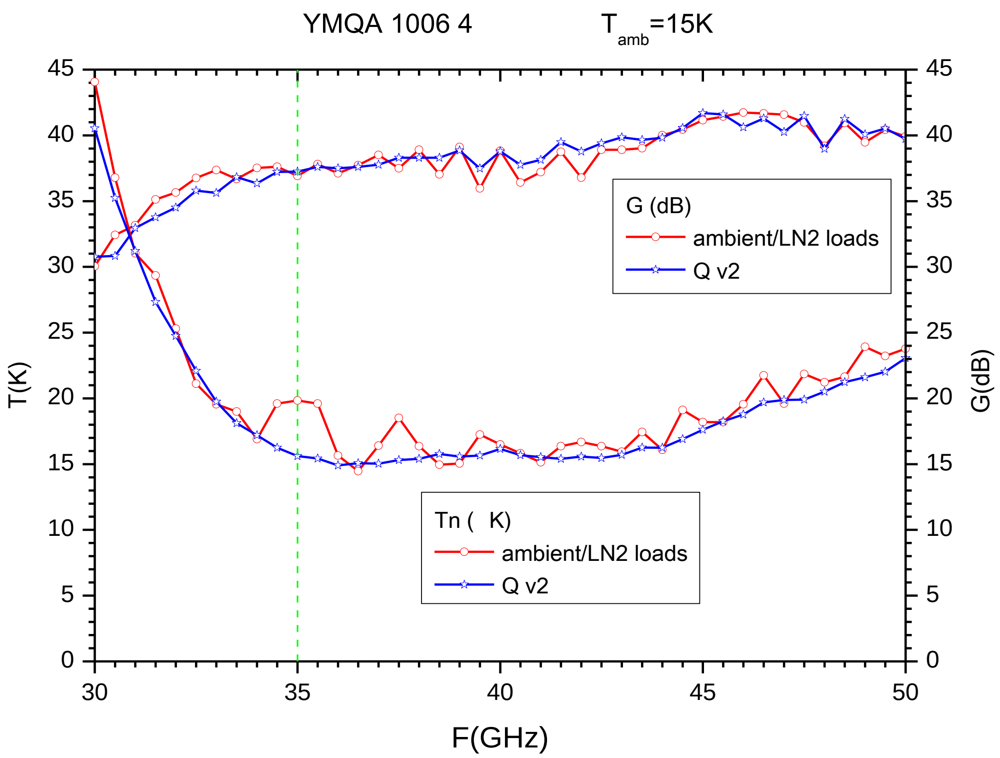

Figure 5. Comparison of the measurements of gain and noise temperature of the YMQA 1006 4 amplifier using the heated load (blue line) against the measurement using ambient/LN2 absorbers (red line).

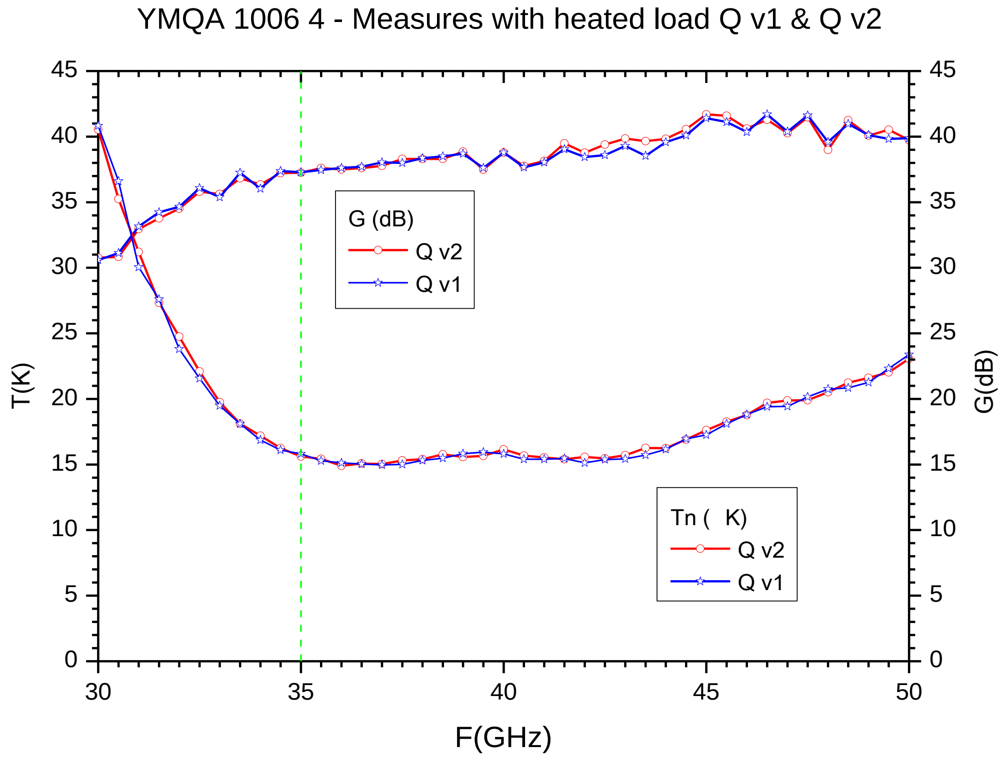

Figure 6. Comparison of the measurements of gain and noise temperature of the YMQA 1006 4 amplifier using the Q v1heated load (blue line) against the Q v2 heated load (red line).

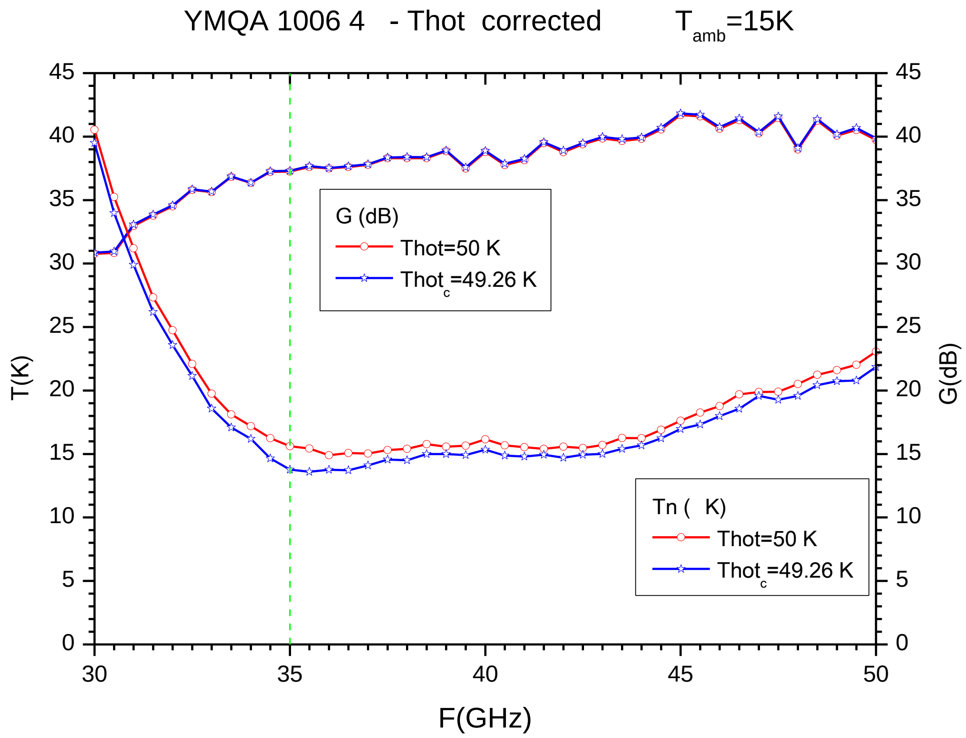

Figure 7. Difference in the noise and gain measurement of the YMQA 1006 4 amplifier with and without the correction of the hot temperature of the heated load: The average noise temperature obtained with the correction is 0.89 K lower (T_{mean}=17.27 K with T_{hot} 50 K and T_{mean}=16.38 K with T_{hot} 49.26 K).

Correction of the hot temperature by the loss in the SS waveguide.

Taking into account the effect of the loss and temperature distribution along the 50 mm stainless steel waveguide with the boundary conditions of a physical temperature of 15 and 50 K respectively on each side, the calculated[9] mean effective noise temperature presented at the input of the amplifier is **49.26 K,** in the 33 - 50 GHz band**.** Figure 7 shows an example of the noise results obtained with (T_{hot} = 49.26 K) and without (T_{hot} = 50 K) correction for the YMQA 1006 4 amplifier. The corrected average noise temperature is **0.89 K (5.2 %)** low than the uncorrected value.

Effect of different hot temperature values.

Figure 8 and Table 3 compare the noise temperature results obtained for the YMQA 1006 4 amplifier for the different values of the hot temperature (35, 50 and 80 K). The average noise temperatures values differ less than 1%.

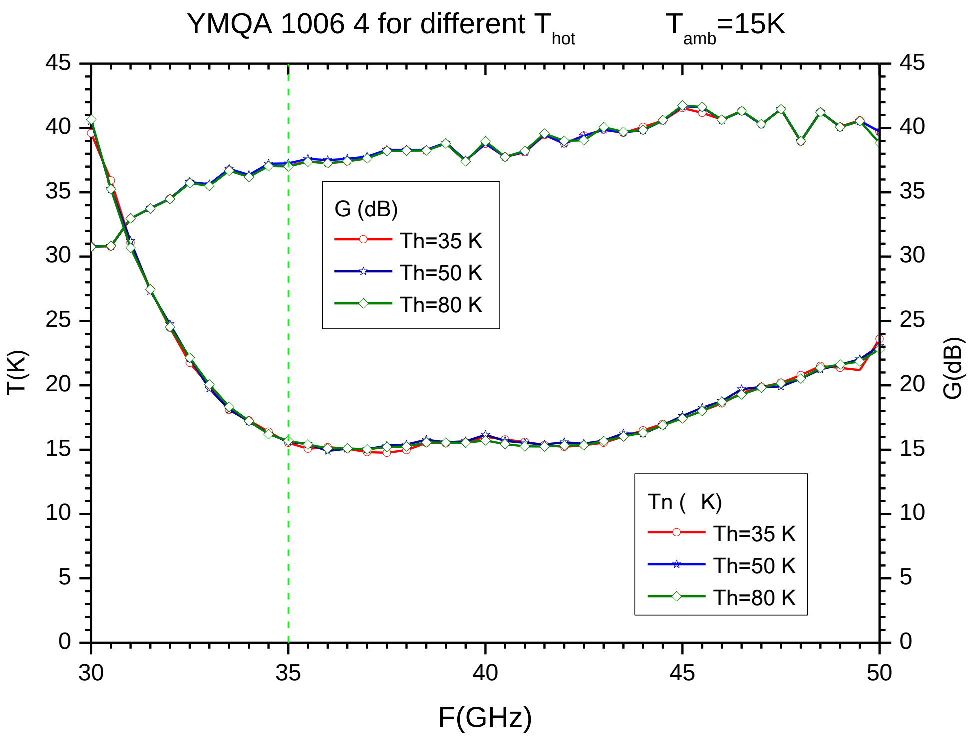

Figure 8. Comparison of the gain and noise temperature obtained using different values of the hot set point. The cold set point was 20 K in all cases.

[9] *Gallego, J.D.; Malo, I.; López, I.; Diez, M.; "Thermal Conductivity and Electrical Loss of Thin Wall Millimeter Wave Stainless Steel Waveguides", in IT-CDT-2015-14. Note that the loss is frequency dependant. An average in the band was used for the practical calculations.*

Table 3. Comparison of the average noise temperature obtained using different values of the hot set point. The cold set point was 20 K in all cases.

Measurement	*T mean (35-50 GHz)*
Thot = 35 K	17.20
Thot = 50 K	17.27
Thot = 80 K	17.26

6. Conclusions.

The new design of the heated load reduces the thermal time constant of the system and so improves the speed of the measurements, reducing the errors due to a possible gain drift of the receiver and the amplifier during the measurement.

The noise measurements of the Q-LNA with the new heated load (v2) are indistinguishable from the measurements with the v1 heated load. This suggests that the new design of the load does not affect to its electrical performance.

In order to improve the accuracy of the measurements with the heated load, the hot temperature value used in the noise measurements must be the mean effective output noise temperature of the load (i.e. the hot physical temperature corrected by the effect of the loss in the stainless steel waveguide). For boundary conditions of 15 and 50 K of temperature respectively on each side of the SS waveguide of our load, the calculated mean effective output noise temperature presented at the input of the amplifier is **49.26 K.** This correction could be significant, especially in the case of extremely low noise amplifiers.