MEASUREMENTS OF GAIN FLUCTUATIONS IN GaAs AND InP CRYOGENIC HEMT AMPLIFIERS

Juan Daniel Gallego
Isaac López Fernández

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ABSTRACT

This report presents the results of the measurements of gain fluctuations of several cryogenic amplifiers, three for 8-12 GHz band and two for the 4-8 GHz band. The objective is to obtain comparative data of one type of GaAs and two types of InP HEMT devices with good cryogenic performance. The data will help in the decision of the device used for FIRST amplifiers and could also provide information needed in the IF system design and in the estimation of the chopper frequency.

1 INTRODUCTION:

The gain fluctuations of cryogenic HEMT amplifiers are small and difficult to measure. However, the new designs of ultra wide band amplifiers using very low noise InP devices have made more important a careful characterization. The effect of gain fluctuations is very important in applications where the other radiometric fluctuations are small, like very low noise receivers with large instantaneous bandwidth. Obviously, the main concern is in receivers for continuum observations, but they can also affect spectral line receivers.

The aim of this work has been to give a rough characterization of gain fluctuations of complete cryogenic amplifiers using equipment readily available in our laboratory. The experimental measurements have been made injecting a stable CW signal (8 GHz) from a HP 83650 B synthesizer and detecting the output power in a narrow band tuned to the carrier frequency. The level of the signal was adjusted using a continuously variable attenuator to obtain a power level of -20 dBm at the output of the amplifier to avoid compression. The fluctuations in the elements used in the system limit the sensitivity of the measurements. However it is possible to appreciate the additional fluctuations introduced by the HEMT amplifiers.

Different schemes to characterize gain fluctuations have been used by other groups. For example, S. Weinreb [1] uses a special bridge working at 10 MHz to obtain higher sensitivity in the measurements of transconductance fluctuations of individual devices. Most of the results reported previously in the literature [2], [3] are obtained with wide band radiometers using thermal noise sources at the input. In our present report, the results presented are measured with a CW signal, not with wide band random noise. In this sense, the fluctuations measured are expected to mimic the effect in one channel of a spectral line receiver. Unfortunately, our system does not provide information on the simultaneous effect at other frequencies in the band of the amplifier. Additional work is needed to clarify weather the fluctuations are simultaneous in the pass band of the amplifier or not.

TABLE I

Devices used in the X band (8-12 GHz) amplifiers tested

Amplifier S/N	1st stage	2nd stage	Tn (K) @ Tamb=15 K
YXF 001	FHX 13 X (Fujitsu) 200×0.25 µm GaAs	FHX 13 X (Fujitsu) 200×0.25 µm GaAs	13.6
YXF 003	TRW 160×0.1 µm InP	FHX 13 X (Fujitsu) 200×0.25 µm GaAs	6.5
YXF 008	ETH 200×0.2 µm InP	FHX 13 X (Fujitsu) 200×0.25 µm GaAs	6.7

2 SYSTEM CALIBRATION:

The spectral density of normalized gain fluctuations of system was measured at the same frequency and signal level used in the measurement of the amplifiers. The measurements were fitted to the following expression:

$$cal(f) = b_1 + b_2 \cdot \left(\frac{1 \cdot Hz}{f} \right)^{\alpha}$$

$$b_1 = 3.4 \cdot 10^{-5} \cdot \frac{1}{\sqrt{Hz}}$$

$$b_2 = 7.6 \cdot 10^{-6} \cdot \frac{1}{\sqrt{Hz}}$$

$$\alpha = 0.9$$

The contribution of the white noise dominates for frequencies greater than 1 Hz, as can be seen in the graph of figure 1.

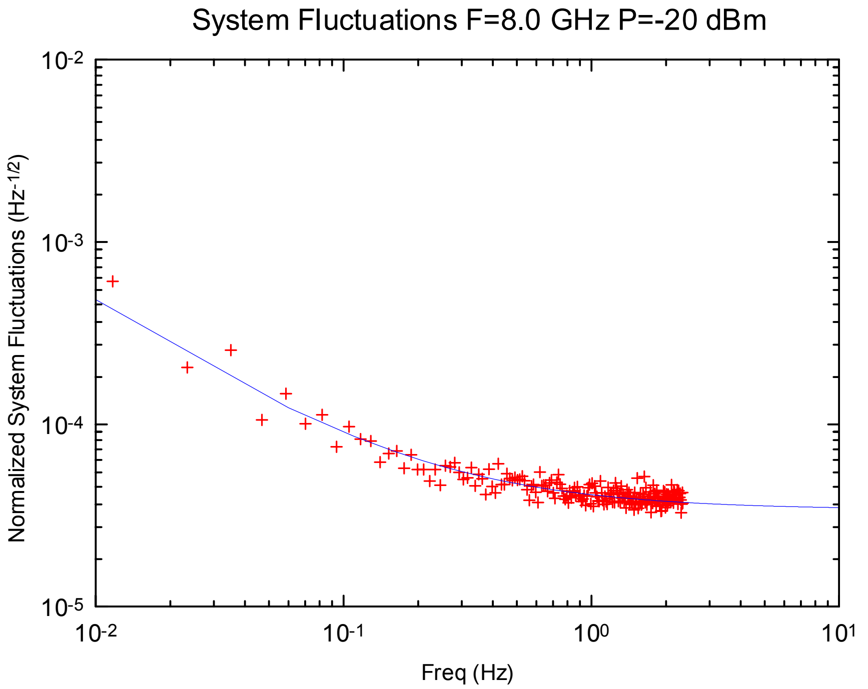

Figure 1: Spectral Density of Normalized Gain Fluctuations of the measuring system. Units are Hz $^{-1/2}$.

3 AMPLIFIER MEASUREMENTS

The amplifiers of table I were measured at room and cryogenic temperature. The data presented in table II has been corrected to subtract the contribution of the fluctuations in the measuring system obtained in section 2. The parameters presented in the table are obtained fitting the experimental spectral density to the following function:

$$S(f) = b \cdot \left(\frac{1 \cdot Hz}{f} \right)^{\alpha}$$

Were S(f) is the Spectral Density of Normalized Gain Fluctuations (units $1/\sqrt{Hz}$). Figure 2 presents one of the measurements obtained (corrected for the fluctuations added by the system) as an example. The value of the system fluctuations is shown in the same graph for reference. The values obtained for the spectral index α are not considered very reliable, since the fitting has been obtained only for one decade of frequency, from 0.1 to 1.0 Hz. The effect of LED illumination in gain fluctuations is very noticeable in the case of the amplifier built with the ETH device in the first stage. In all the cryogenic measurements a clear and sharp line appeared at 1 Hz , which is the cycle of the CTI 1020 refrigerator. The amplitude of this line probably shows the sensitivity of the gain respect to temperature. Unfortunately, the value of the amplitude of the temperature oscillations is not known. The value of the peak is provided as a comparison of the relative sensitivity of different amplifiers.

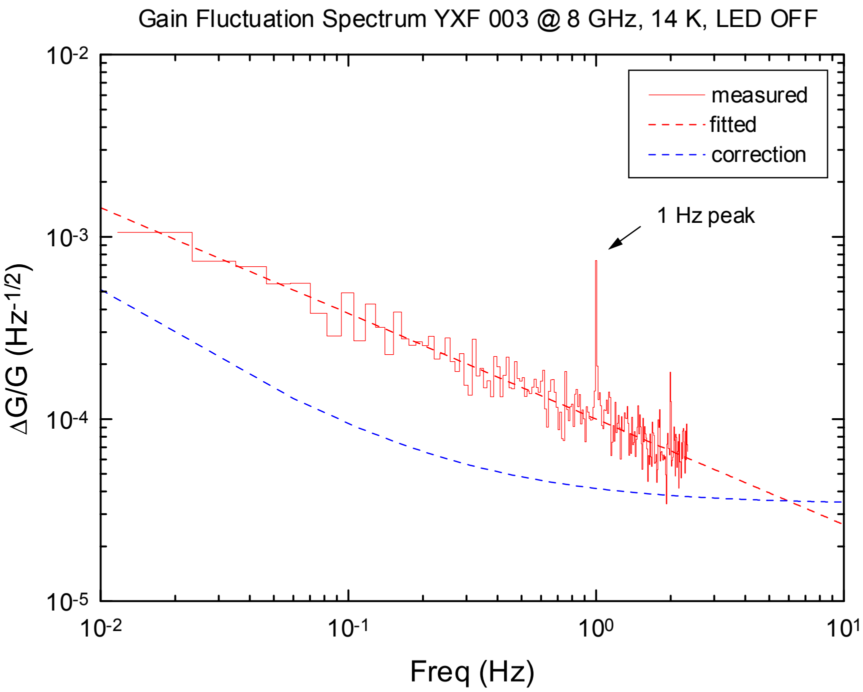

Figure 2: Example of calibrated measurement of the Spectral Density of Normalized Gain Fluctuations of Amplifier YXF 003. The measured data presented has been corrected to eliminate the contribution of system fluctuations. The value of the correction is also shown in the graph as a reference. The peak appearing at 1 Hz is due to the cycle of CTI 1020 refrigerator. A smaller peak at 2 Hz is also visible.

TABLE II

Results of measured gain stability of 8-12 GHz amplifiers measured at 8 GHz

AMPLIFIER	297 K		14 K *LED OFF*		14 K *LED ON*		Peak at 1 Hz ($\times 10^{-4}$)	
	b ($\times 10^{-5}$ 1/√Hz)	α	b ($\times 10^{-5}$ 1/√Hz)	α	b ($\times 10^{-5}$ 1/√Hz)	α	*LED OFF*	*LED ON*
YXF 001	2.8 ± 1.1	0.50	4.8 ± 1.0	0.70	7.7 ± 1.3	0.76	5.9	6.6
YXF 003	1.8 ± 1.3	0.51	10. ± 2.0	0.58	11. ± 1.9	0.52	7.4	7.6
YXF 008	1.4 ± 1.1	0.66	7.8 ± 1.6	0.51	11. ± 1.9	0.68	5.2	5.7

4 DEVICE DATA

The contribution of the different types of devices used, taking into account the composition of each amplifier is shown in table III. The values of table III are deduced directly from the results of table II, assuming identical contribution of all the FHX 13 X devices involved. Only the value of b (value of the spectrum at 1 Hz) is shown, since the value of the spectral index α is considered imprecise. The values shown in parenthesis for the TRW and ETH devices at room temperature are only estimations, since the room temperature data is too noisy, and the value obtained in the calculation was wrong, due to the large errors involved The data obtained for cryogenic temperature is more reliable. The effect of LED illumination is almost unnoticeable in the TRW devices.

TABLE III

Results of gain stability of HEMT

DEVICE	297 K b ($\times 10^{-5}$ 1/√Hz)	14 K *LED OFF* b ($\times 10^{-5}$ 1/√Hz)	14 K *LED ON* b ($\times 10^{-5}$ 1/√Hz)
FHX 13 X	2.0 ± 0.8	3.4 ± 0.7	5.4 ± 0.9
TRW 160	(1.3) ± 1.5	9.4 ± 2.1	10. ± 2.0
ETH 200	(1.0) ± 1.3	7.0 ± 1.7	10. ± 2.0

5 DEVICE REPEATABILITY

A similar set of measurements was carried out with other amplifiers to check the variations between devices of the same batch. For this test two different 4-8 GHz amplifiers were measured with a CW signal of 6 GHz and output power level of –20 dBm. The amplifiers used for this test (YCF 2001 and YCF 2005) were built with two stages of ETH devices of the same batch (but different from the batch used in the 8-12 GHz amplifier S/N YXF 008). The error in the measurement is not shown in table IV, but is similar to the values of the first line of table III.

TABLE IV

Results of gain stability of ETH HEMTs in 4-8 GHz amplifiers measured at 6 GHz.

DEVICE	**297 K** **b** ($\times 10^{-5}$ 1/√Hz)	**14 K** *LED OFF* **b** ($\times 10^{-5}$ 1/√Hz)	**14 K** *LED ON* **b** ($\times 10^{-5}$ 1/√Hz)
ETH 200 (YCF 2001)	3.2	2.8	35.
ETH 200 (YCF 2005)	5.0	7.5	36.

6 CONCLUSIONS

From the results presented in table III, the performance of the two InP devices tested is quite similar in cryogenic gain stability, with a small advantage of the ETH device. Both devices are clearly worst than the GaAs device measured. It is interesting to note that the LED illumination has a negative impact on the stability in almost all cases, with the exception of TRW device. This fact contradicts other results presented in the literature [2], [3].

The results obtained with ETH devices in the 4-8 GHz amplifiers showed results with large dispersion. In one case the stability without illumination was the best measured (even better than in GaAs), and in the other case the result was similar to the one obtained in the 8-12 GHz amplifier. The reason for the large degradation with illumination is not clear, but could be related with the low bias point of these amplifiers. The excellent result obtained in YCF 2001 demonstrates the potential of the ETH devices. Unfortunately, this characteristic does not seem to be repeatable. It is interesting to note that ETH devices are unpassivated, and usually unpassivated devices have higher 1/f noise [4].

Finally, for comparison, the results of [2] give a value of b=17 10^{-5} 1/√Hz per device at 50 K. The value was obtained for unpassivated InP devices of 0.1×50 µm made by Hughes.

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