Preliminary measurements of the Gain Fluctuation of the 22 GHz receiver of the 40m Yebes Antenna

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ABSTRACT

Gain Stability of Radio Astronomy receivers a very important issue, since it can severely limit their sensitivity, especially for wide-band continuum observations. Its importance is well known since the early years of Radio Astronomy and smart receiver architectures (Dike switching) were developed to avoid its detrimental effect. However, it has not been until recent high-performance collaborative projects (MAP, Plank, Herschel, ALMA) that serious quantification methods have been used to specify gain fluctuations of receiving systems and components. This technical note presents the results of applying these quantification methods to the 22 GHz Yebes receiver in the continuum mode configuration. The Spectrum of Normalized Gain Fluctuation (SNGF) and the Allan variance are calculated and analyzed. The interpretation of the results shows that besides the expected fluctuations with $1/f^{\alpha}$ spectrum there is an additional source of fluctuations with flat spectrum with dominates over the radiometric noise. This effect prevents reaching the ultimate sensitivity achievable from the receiver. The cause is still unknown.

The results obtained show that at least a factor of 10 could be improved in wide band continuum measurements. However, the investigation of this issue will be an important effort, since gain stability measurements of components and systems are within the more complex and time consuming to be made on low noise receivers. The tests should be carefully planed and the time devoted should be weighted against the results to be obtained. Otherwise this could be an endless effort.

CONFIGURATION

The stability of the receiver was measured with an absorber at ambient temperature on top of the window of the 22 GHz receiver, with the system cooled at about 20 K and stabilized. The complete IF band of one of the two polarizations was sent to a continuum detector (OAY 14) in the backend room. The DC output of the detector was sent to a Keithley DMM datalogger were it was integrated, digitized and sent to the computer. The integration time is 1 second. The results were logged into an ASCII files. The test lasted 16 hours.

In a second test one of the polarizations was routed as previously described while the other was sent to the VLBI terminal and its total power was measured by the built-in continuum detector. As before, the results were logged into ASCII files with integration time of 1 second. This test lasted 48 hour although the VLBI terminal took data for longer lime (65 hours).

It is assumed that the fluctuations of temperature of the input load and receiver noise are negligible compared with changes in gain of the system. Ideally, the test should be performed with an ambient load stabilized in temperature by a proportional controller. As this item was not available, we had to rely in the stability of ambient temperature. During the first test the ambient temperature log (receiver cabin) registered variations of 2.5 K pp. In the same period the output voltage of the receiver showed a variation equivalent to about 25 K pp, which is about ten times the variation of the load. The stability of the noise temperature of the receiver can be estimated from the variations of temperature inside the cryostat and it is expected to be well below 1 K pp.

For the data analysis the log files were split into shorter files (typically 801 or 14001 records) to facilitate the processing. This was done with a MathCAD routine. The rest of the analysis was performed with modified MathCAD routines previously used for measurement of stability of cryogenic amplifiers.

DEFINITIONS

Let G(t) be a random function of time. It could be, for example, the normalized gain (or power) of a receiver. *Allan Variance* σ^2 is defined as:

$$s^{2}(t) = \frac{1}{2}\left\langle \left(\overline{G}(t+t) - \overline{G}(t)\right)^{2} \right\rangle \qquad [1]$$

Were $\overline{G}(t)$ and $\overline{G}(t+t)$ represent the average of the function *G* at times t and $t + \tau$ respectively, and the brackets represent the expected value.

Let S(f) be the <u>S</u>pectrum of <u>N</u>ormalized <u>G</u>ain <u>F</u>luctuation (SNGF). S(f) can be calculated numerically by Fourier transformation of the gain G(t). There are numerous programs and subroutines available to perform the calculation. As the normalization criteria is not always known and may vary between different programs is convenient to check the values obtained. This can be easily done using these simple tests:

$$\begin{aligned} &S(0) = \text{mean}(G(t)) = 1 \\ &\int_{f_{\min}}^{f_{\max}} \left|S(f)\right|^2 \cdot df = \text{var}(G(t)) \end{aligned} \qquad [2]$$

That is, for cero frequency the value of the spectrum should be equal to the DC (average) value of the gain (1 for normalized gain) and the integration of the power spectral density should give its variance (classical, not Allan).

It can be demonstrated that, with the definition of σ given above, the transformation between the unilateral spectral density and the Allan Variance is given by:

$$s^2(t) = 2 \cdot \int_0^{\infty} (S(f))^2 \cdot \frac{\sin^4(p \cdot t \cdot f)}{(p \cdot t \cdot f)^2} \cdot df \qquad [3]$$

Being S(f) spectral density of G (SNGF) with dimensions $1/\sqrt{Hz}$.

Note that for a total power radiometer with instantaneous bandwidth BW with a pure blackbody noise source at the input and no gain fluctuation the Allan Variance and the spectral density of the normalized power detected will be:

$$s^2(t) = \frac{1}{BW} \cdot t^{-1} \qquad [4]$$

$$S(f) = \sqrt{\frac{2}{BW}} \qquad [5]$$

That is, the radiometric noise will appear with a slope of -1 in the time domain and as white noise in the frequency domain.

In the case of using a black body noise source with a receiver with fluctuating gain, the output power will show an Allan Variance with the combination of [1] and [4] and a SNGF with the addition of [5].

MEASUREMENTS

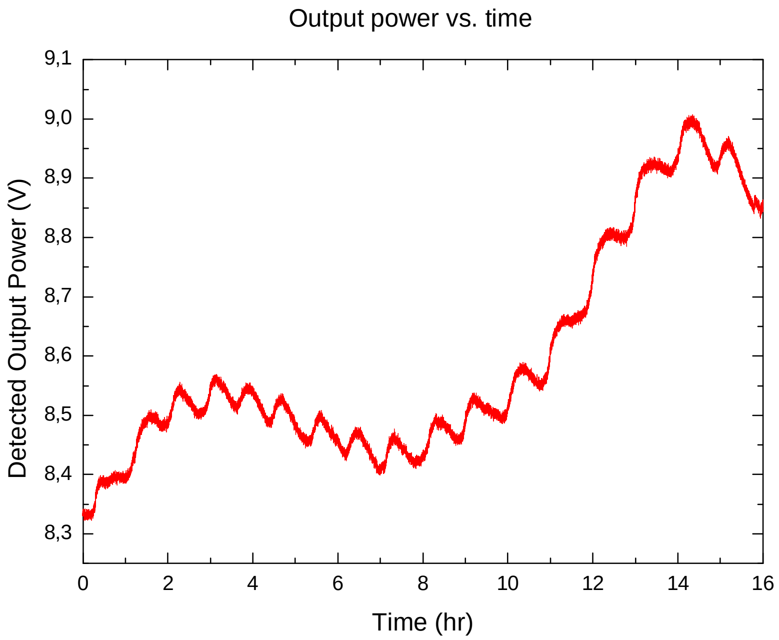

Figure 1: Initial scan of power detected by OAY 14 with 1 second integration time.

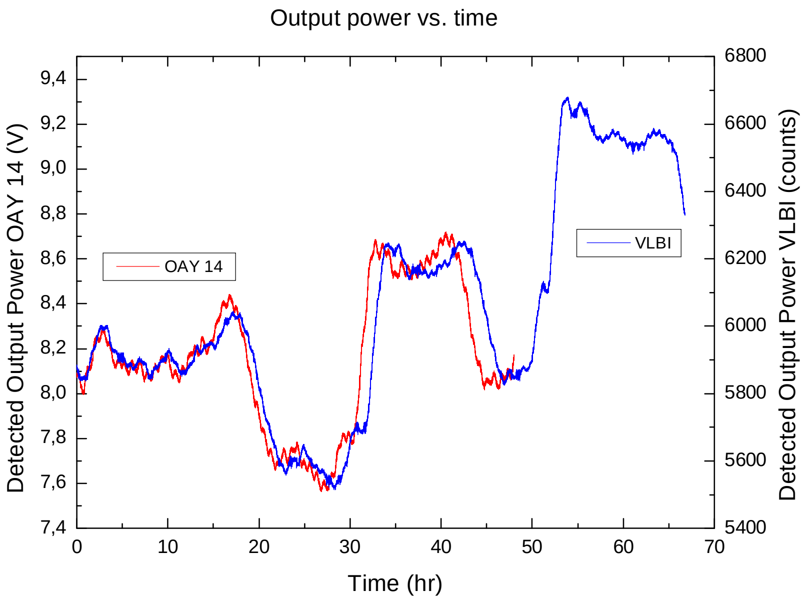

Figure 2: Comparison of power detected by OAY 14 and VLBI terminal continuum detector. Each detector was connected to a different polarization in the receiver.

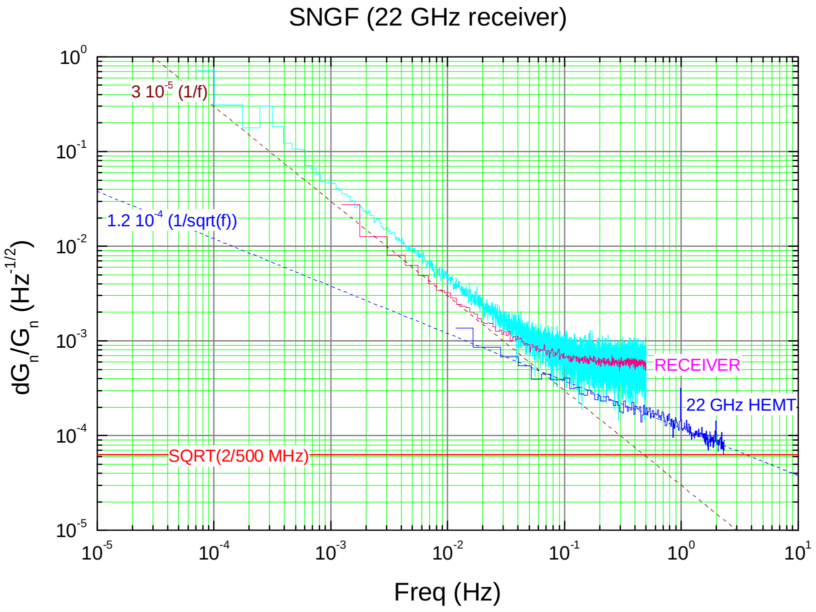

Figure 3: Spectrum of Normalized Gain Fluctuations (SNGF) of the complete 22 GHz receiver. The violet curve corresponds to an average of scans of 801 sec total time, and the cyan to scans of 14001 seconds. The radiometric noise and the SNGF of a 22 GHz InP cryogenic amplifier are also shown for comparison.

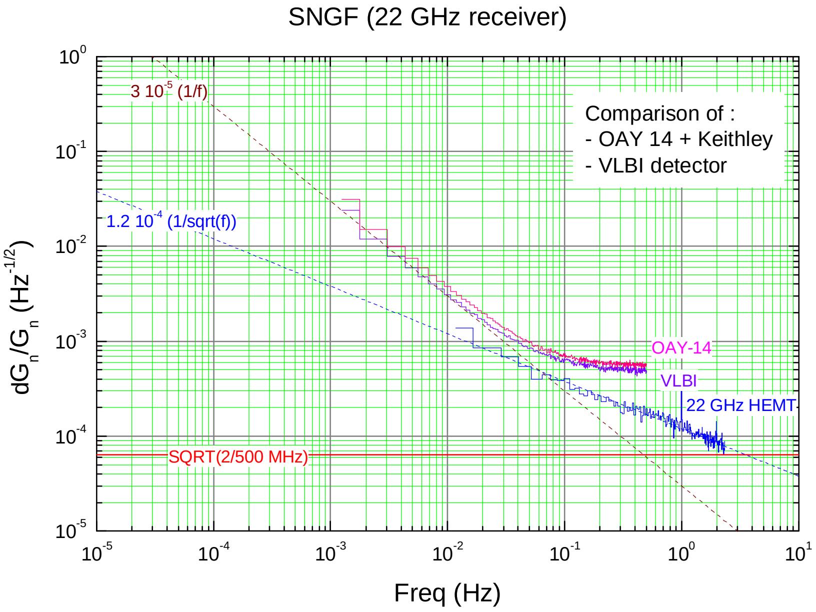

Figure 4: Comparison of the SNGF of the complete 22 GHz receiver detected with OAY 14 and VLBI built-in continuum detector.

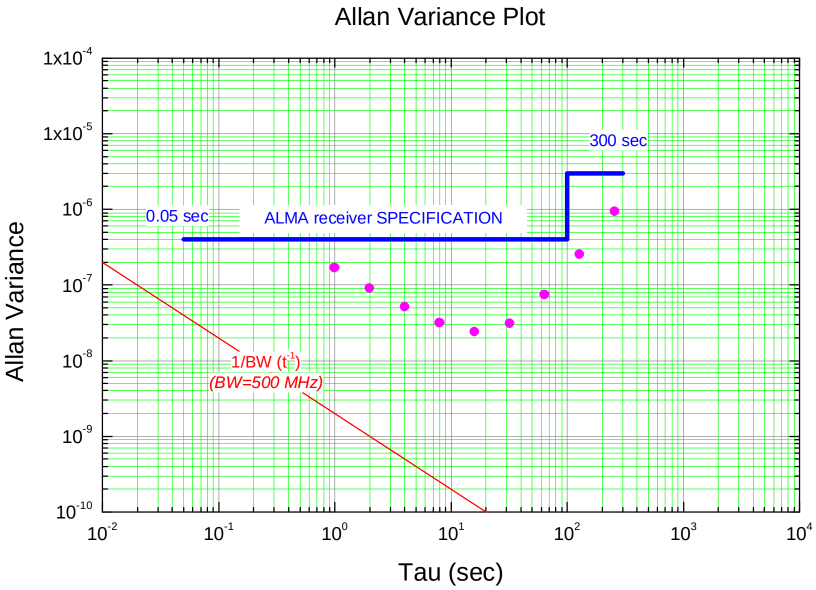

Figure 5: Allan variance of the complete 22 GHz receiver with OAY 14 detector. The specification of ALMA for a complete cartridge and the ideal radiometric noise (BW=500 MHz are also shown for comparison.

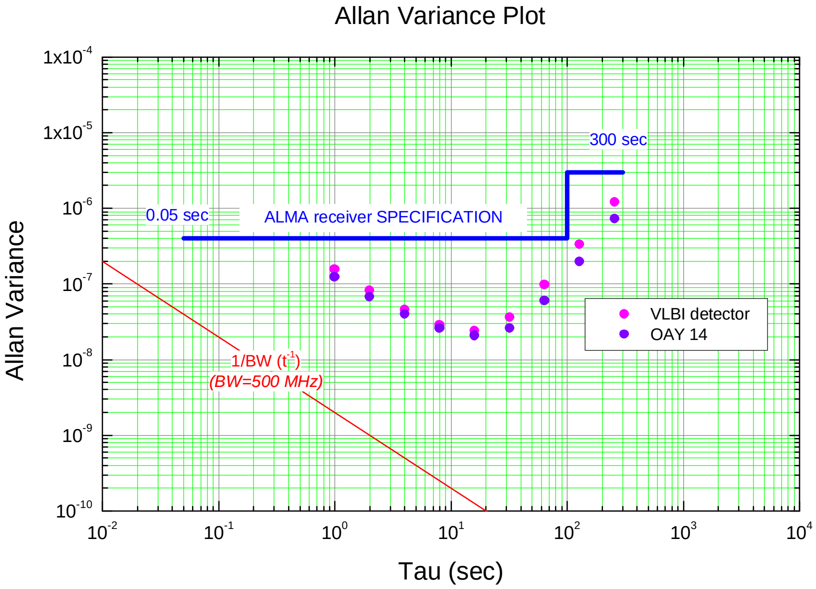

Figure 6: Comparison of Allan variance of the complete 22 GHz receiver with OAY 14 and with the built-in VLBI terminal continuum detector.