MEMO

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Subject: First inspections of Tsys determination and correlated noise of the 4 channels of PAON-2 using observations of 9th Oct. 12.

1 Introduction

The data used in this MEMO correspond to the Sun transit collected the 9th Oct.12 (11h01 to 12h11 UTC) as well as noise collected the same day (14h36 to 15h46 UTC) after the manual repositioning of the two dishes: East dish in azimuth to be as much as possible parallel to the West dish, and both dishes roughly at altitude 30.0-30.5°.

We use the four auto-correlations for channels 0, 1, 2, 3 (polarization West V, East V, West H, East, H)[1] as well as the 6 cross-correlations 01, 02, 03, 12, 13, 23. These visibilities are obtained offline after data transfer to CCIN2P3. The DAQ parameters yield 1kHz trigger and 16µs per sample (ie. BAO paquet), then we make average over 2000 samples corresponding to 32ms ON Sky and 1MHz frequency band, but no filtering against RFI have been applied. We use for this MEMO only the 1MHz around 1415MHz.

We investigate the Tsys measured both by signal fluctuations as well as signal level which is attributed to Sky background, as well as possible impact of correlated noise.

2 Sun transit: a rough calibration

The 9th Oct. 12 the NOAA web site[2] indicates the Sun radio emission flux (unit: 10^{-22} W/m^2/Hz):

2012 Oct 9

245	25	22	17	-1	-1	-1	-1
410	40	41	37	-1	-1	-1	-1
610	59	-1	54	-1	-1	-1	-1
1415	84	84	77	-1	-1	82	-1
2695	97	104	102	-1	-1	102	-1
2800	-1	-1	-1	105	106	-1	109
4995	145	152	141	-1	-1	139	-1
8800	280	280	279	-1	-1	290	-1
15400	561	526	568	-1	-1	-1	-1

To convert the flux (*F*) into temperature (*T*), we use the following formula:

$$T = F \times \frac{1}{2k} 10^{-22} \pi R^2 \eta \approx 12.8 \times F$$

where we have used R = 1.5m and η = 50%. For F = 84 snu we then get T_Θ = 1076K.

[1] Note that still remains an H $\Leftrightarrow$V ambiguity

[2] http://www.swpc.noaa.gov/ftpdir/lists/radio/30day_rad.txt

This temperature is used to calibrate roughly each polarization signal using the transit registered the same day thanks to the auto-correlations. For instance Figure 1 shows the Sun transit registered by the channel 0. From this graph using the Min and Max, it is extracted the calibration coefficient for each polarization defined as

$$C_p = \frac{T_\Theta}{(Max - Min)_p}$$

The Table 1 reports the 4 calibration coefficients where we notice a large dispersion among the 4 polarizations.

Table 1

Polar. P	C_p [K/a.u]
0	$1.94\ 10^{-2}$
1	$4.73\ 10^{-2}$
2	$3.51\ 10^{-2}$
3	$2.17\ 10^{-2}$

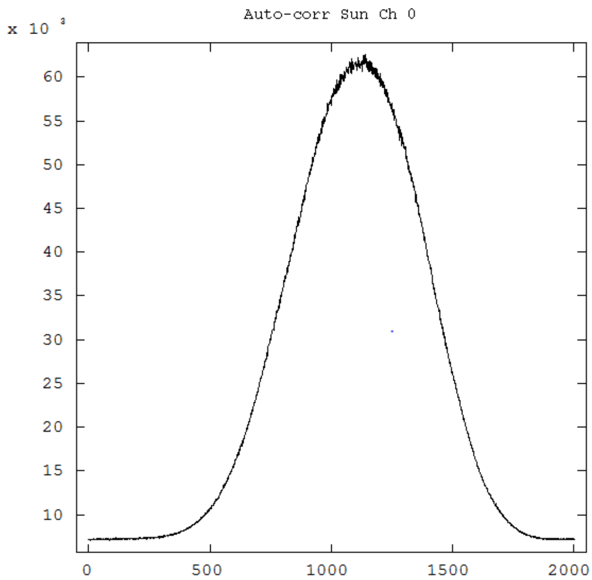

Figure 1 Auto-correlation channel 0 during the Sun transit.

3 Noise data

3.1 The auto correlations

The same day later far from the Sun transit data have been taken in the same dish position. The Figure 2 shows the 4 auto-correlations during the observations (~4000sec total). The level is slowly increasing with time. We absorb this increase by a simple linear fit from which we obtain 2 information: first the base level at mid-term of the run (bin 1000), and second the fluctuation histogram which in turn is fit with a Gaussian to extract the sigma (Figure 3).

From the base levels and the calibration coefficient we can compute a system temperature Tsys_1 if the signal is fully attributed to Sky background. In an other hand, using the sigma of the signal fluctuations, reminding that we have integrated over 1MHz and 32ms, with the same calibration coefficients we can extract also a system temperature Tsys_2.

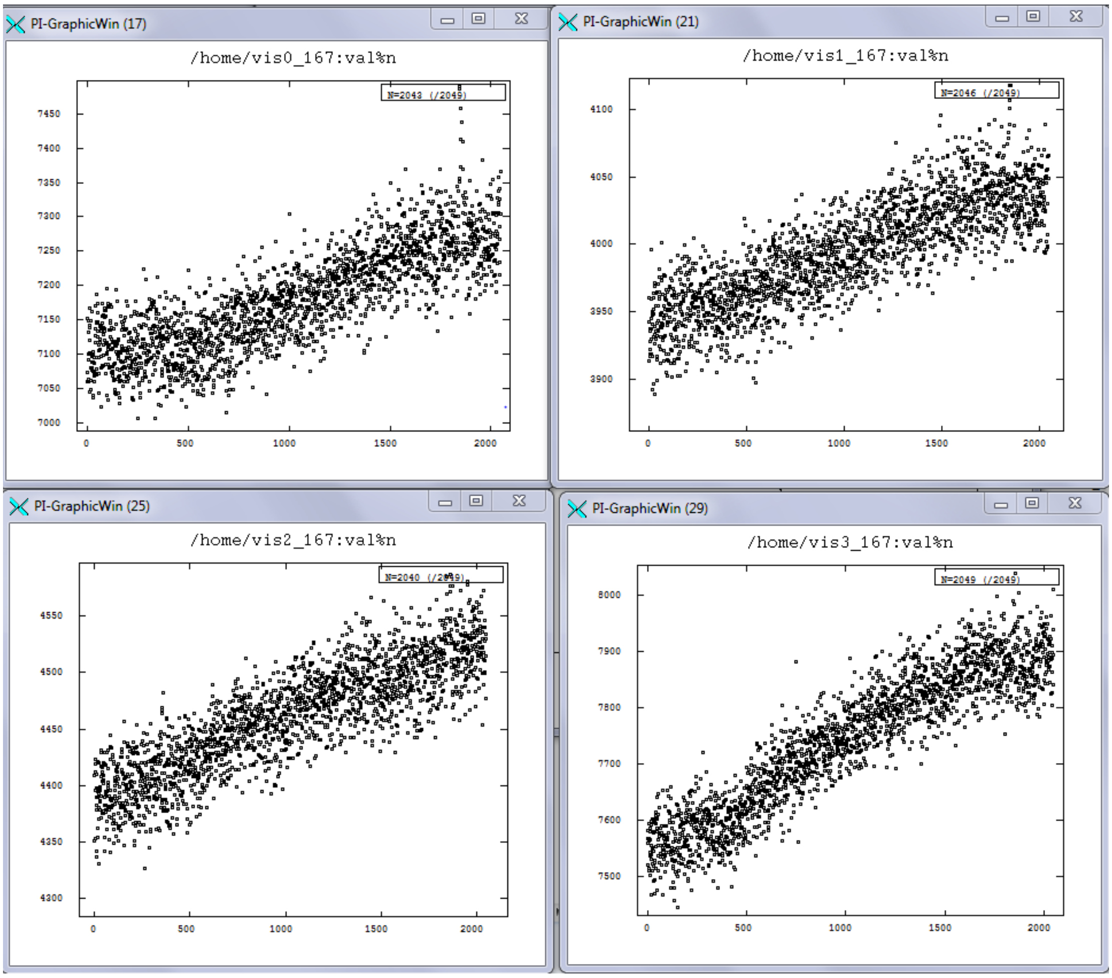

Figure 2 Auto-correlation signal levels during the noise observation. From top to bottom and from left to right is presented the signal of the 4 polarizations 0, 1, 2, 3.

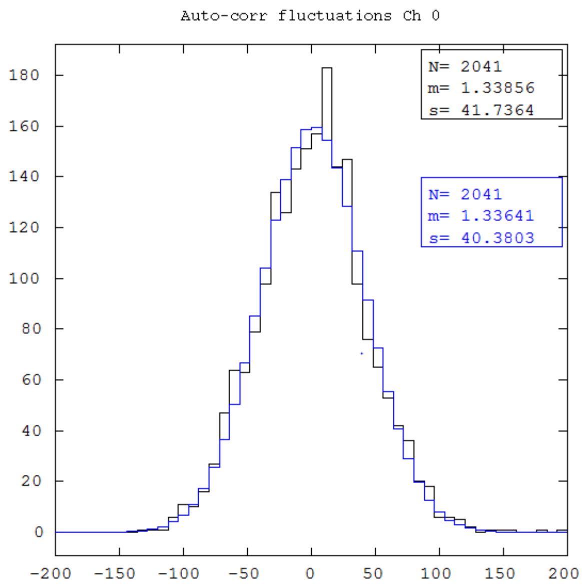

Figure 3 Signal fluctuations during noise observation after removing a slow increase of the base level.

On Table 2 are reported the two system temperatures extracted. We notice quite good agreement between the two determinations of the Tsys values except for the channel 3. It is reminded that the two values should be equal in the case of white noise. We note also that West polarizations (0 & 2) are less noisy that the East ones (1 & 3).

Table 2

Polar p	Base level (a.u)	Tsys_1 (K)	σ fluctuations (a.u)	Tsys_2 (K)
0	$7.17\ 10^3$	139	41.74	145
1	$3.99\ 10^3$	189	22.12	187
2	$4.46\ 10^3$	156	25.94	163
3	$7.74\ 10^3$	168	46.77	181

3.2 The cross-correlations

Using the cross-correlations is another way to investigate noise sources. We then use the real and imaginary parts of the 6 cross-correlations (01, 02, 03, 12, 13 and 23). We proceed similarly to the auto-correlations to extract the base levels as well as the sigma of the fluctuations. Table 3 gives the net results. It is worth to mention (but not shown) that all the cross-correlations are very constant during all the observations.

Table 3

Cross Correlation	Base level (a.u)	σ fluctuations (a.u)
Re(01)	$1.02\ 10^3$	20.65
Re(02)	$1.13\ 10^3$	21.87
Re(03)	$1.03\ 10^3$	30.48
Re(12)	$1.02\ 10^3$	16.11
Re(13)	$1.03\ 10^3$	21.97

Re(23)	1.04 10^3	23.76
Im(01)	−2.08	20.51
Im(02)	+5.15	22.16
Im(03)	−2.85	27.90
Im(12)	−1.41	15.69
Im(13)	−1.92	22.67
Im(23)	+3.20	24.14

From uncorrelated white noise, we would expect 0 mean (ie. base level) for all these quantities. As this is clearly not the case, we investigate the possibility of correlated noise among all the channels.

3.3 Noise model

In order to account for the results presented in the different tables, we set up the following simple model where each channel "*i*" is described by a complex signal represented by:

$$sig_i = \eta_i \left(s_i^R + \varepsilon_i n^R \quad s_i^I + \varepsilon_i n^I \right)$$

With η_i represent a global real gain (relative to signal of channel 0 in practice), (s_i^R, s_i^I) the real and imaginary independent parts of the signal, ε_i a real coefficient of addition of a common noise (n^R, n^I) to all channels. We also suppose that the random variable follow the same Gaussian distribution, that is to say:

$$s_i^R, s_i^I, n^R, n^I \approx \mathrm{N}(0,\sigma)$$

Then, the mean and variance of the auto-correlations and real/imaginary parts of the cross-correlations can be computed (note the vismfib program does not normalize the visibility):

$$\mu[Vis_{ii}] = 2N\eta_i^2(1+\varepsilon_i^2)\sigma^2$$
$$Var[Vis_{ii}] = 4N\left(\eta_i^2(1+\varepsilon_i^2)\sigma^2\right)^2$$
$$\mu[\mathrm{Re}[Vis_{ij}]] = 2N\varepsilon_i\varepsilon_j\eta_i\eta_j\sigma^2$$
$$Var[\mathrm{Re}[Vis_{ij}]] = 2N\eta_i^2\eta_j^2\left(1+\varepsilon_i^2+\varepsilon_j^2+2\varepsilon_i^2\varepsilon_j^2\right)\sigma^4$$
$$\mu[\mathrm{Im}[Vis_{ij}]] = 0$$
$$Var[\mathrm{Im}[Vis_{ij}]] = 2N\eta_i^2\eta_j^2\left(1+\varepsilon_i^2+\varepsilon_j^2\right)\sigma^4$$

Where N stands for the total number of effective samples used to compute the visibilities, that is to say $N = \Delta\tau\ \Delta\nu = 32{,}000$ in our case.

Qualitatively, this model keeps the pure white noise result concerning the ratio $\mu^2/Var = N$ for the auto-correlations, while it rises only a non zero mean value for the real part of the cross-correlations.

Quantitatively this model shows interesting agreements as playing a little bit with the formula one can guess a set of input numerical values: $\sigma \sim \sqrt{10^{-1}}$a.u, $\eta_0 = 1$ (by convention), $\eta_1 = 0.640$, $\eta_2 = 0.743$, $\eta_3 = 0.945$, $\varepsilon_0 = 0.35$, $\varepsilon_1 = 0.60$, $\varepsilon_2 = 0.50$, $\varepsilon_3 = 0.60$. We then get the numerical values shown on Table 4.

Table 4

Visibility	Mean (a.u)	Sigma (a.u)	Mean (a.u) Imag.	Sigma (a.u) Imag.
Vis_{00}	7.2 10^3	40		
Vis_{11}	3.6 10^3	20		
Vis_{22}	4.4 10^3	25		
Vis_{33}	7.8 10^3	43		
Vis_{01}	0.9 10^3	20	0	20
Vis_{02}	0.8 10^3	22	0	22
Vis_{03}	1.3 10^3	30	0	29
Vis_{12}	0.9 10^3	16	0	15
Vis_{13}	1.4 10^3	22	0	20
Vis_{23}	1.3 10^3	24	0	23

4 Summary and outlook

In this MEMO it has been investigated the statistical behavior of the auto & cross correlations of all the 4 channels registered during Sky observation the 9th Oct. The Sun transit observed the same day has been used to scale the arbitrary units. Although the Sun is not a suitable source for precise measurement, a first system temperature has been extracted from auto-correlations and turns out to be 140-190K depending of the channels and the way to extract the information.

Looking at cross-correlations has show a clear noise correlation among all the channels. A simple model has been introduced including a common noise and it turns out to reproduce quite well the observations. As consequences, the Tsys value without this correlated noise would be ~ 40% less in some channels (ie. factor $1+\varepsilon^2$), and the base level of the real part of the cross-correlations are clearly attributed to this correlated noise.

As same LNA will be soon replaced, this kind of study would have to be redone and extended to the whole frequency band.