MEMO

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PAON2/Sun/30.11.12

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Subject: First attempt to fit Sun transit with PAON-2

1 Introduction

The data used in this MEMO correspond to the Sun transit collected the 13th Oct.12 after manual repositioning of the two dishes: the East dish was moved in azimuth to be as much as possible parallel to the West dish, and both dishes point roughly at altitude 30.0-30.5° corresponding to Sun transit 6th Oct. 12.

The visibilities used are the four auto-correlations for channels 0, 1, 2, 3 (polarization West V, East V, West H, East, H), and the two main cross-correlations 01 and 23. These visibilities are obtained offline after FFT performed online at Nançay and data transfer to CCIN2P3. It is used 2sec time integration (1kHz trigger, 2000frames) and averaging on 1MHz band width, but no filtering against RFI have been applied.

The time evolution of the visibilities is presented on Figure 1. The purpose of this MEMO is to investigate the possibility to fit a set of parameters describing these visibilities.

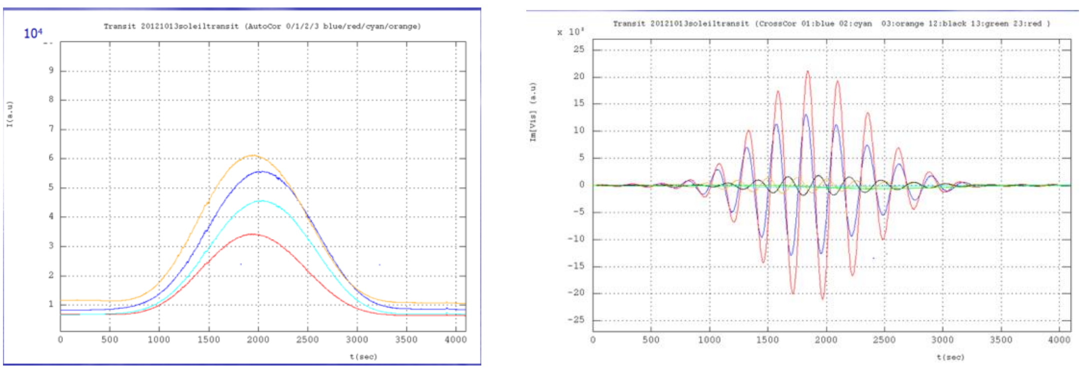

Figure 1 Auto-correlations and cross-correlations observed during a Sun transit.

2 The model

The model used is a set of analytical formula with phenomenological parameters.

First the beam shape is taken from an ideal circular dish diffraction pattern (J_1: Bessel function):

$$Beam[x] = 2J_1[x]/x \quad \textbf{Eq. 1}$$

Of course, J. Pezzani has designed a feed which suppress the secondary lobes, but for the time being, I have not yet an analytical description and this is let for future improvement. Then, each channel response can be parametrized as:

$$sig[t; s_{\max}, R, \Omega, t_{\max}] = s_{\max} Beam\left[2\pi \frac{\nu_0}{c} R \sin\Omega(t - t_{\max})\right] \qquad \textbf{Eq. 2}$$

With ν_0 the central frequency on a band width of 1MHz, R an effective radius of the dish, t_{max} the time of maximum signal and Ω an angular velocity which in principle is equal to 7.29 10^{-5} sin (λ+alt.) ~ 7.1$10^{-5}$ rad/sec. Hereafter, Ω is fixed to be the same for all channels. The t_{max} parameter is left independent for all the channels even in the same feed. The R parameter has also been left independent for all the channels too even if a priori there is a circular symmetry.

The 4 auto-correlations are then modeled by:

$$\left|\begin{array}{l}
Auto_0[t; n_0, s_{\max,0}, R_0, \Omega, t_{\max,0}] = n_0 + \left\| sig\left[t, s_{\max,0}, R_0, \Omega, t_{\max,0}\right]\right\|^2 \\
Auto_1[t; n_1, s_{\max,1}, R_1, \Omega, t_{\max,1}] = n_1 + \left\| sig\left[t, s_{\max,1}, R_1, \Omega, t_{\max,1}\right]\right\|^2 \\
Auto_2[t; n_2, s_{\max,2}, R_2, \Omega, t_{\max,2}] = n_2 + \left\| sig\left[t, s_{\max,2}, R_2, \Omega, t_{\max,2}\right]\right\|^2 \\
Auto_3[t; n_3, s_{\max,3}, R_3, \Omega, t_{\max,1}] = n_3 + \left\| sig\left[t, s_{\max,3}, R_3, \Omega, t_{\max,1}\right]\right\|^2
\end{array}\right. \qquad \textbf{Eq. 3}$$

Notice that the noise parameters (n_i) which count for a non zero value of auto-correlation in absence of input sky signal as a dimension of s_{max}^2.

The 2 main cross-correlations which correlate the signals from polarizations of same orientation in the two feeds are modeled by:

$$\left|\begin{array}{l}
Cross_{01}[t; n_{01}, \eta_{01}, \Omega, s_{\max,0}, R_0, t_{\max,0}, s_{\max,1}, R_1, t_{\max,1}] = n_{01} + \\
\eta_{01}\,\mathrm{Im}\left[\begin{array}{l} sig[t, s_{\max,0}, \Omega, R_0, t_{\max,0}] \times \\ \left(sig[t, s_{\max,1}, \Omega, R_1, t_{\max,1}] Exp[-2\pi i \frac{\nu_0}{c} b_{WE} \sin\Omega(t - t_{\mathrm{int}01})]\right)^* \end{array}\right] \\
Cross_{23}[t; n_{23}, \eta_{23}, \Omega, s_{\max,2}, R_2, t_{\max,2}, s_{\max,3}, R_3, t_{\max,3}] = n_{23} + \\
\eta_{23}\,\mathrm{Im}\left[\begin{array}{l} sig[t, s_{\max,2}, \Omega, R_2, t_{\max,2}] \times \\ \left(sig[t, s_{\max,3}, \Omega, R_3, t_{\max,3}] Exp[-2\pi i \frac{\nu_0}{c} b_{WE} \sin\Omega(t - t_{\mathrm{int}23})]\right)^* \end{array}\right]
\end{array}\right. \qquad \textbf{Eq. 4}$$

New parameters n_{01} and n_{23} have been introduced to account for possible correlated noise. The East-West baseline is noted b_{WE}, and two new reference time $t_{int\ 01}$ and $t_{int\ 23}$ are introduced as they can be different from the time of maximum of the auto-correlations. Notice also that I have introduced two parameters η_{01} and η_{23}. They may account for possible fringe dilution effect originating from a source extension of the same order of magnitude than the beam size.

If we list Eq. 3 and Eq. 4, we end with more than 20 parameters to account for the visibilities of 2 dishes. But, we can cast the global minimization problem into smaller independent minimizations as described in the next section.

3 Parameter determination

The model detailed in the previous section has been used to fit the 6 auto & cross correlations as function of time varying the central frequency ν_0 by 1MHz steps. The fit parameters of the auto-correlations are used as fixed parameters for the cross-correlations. This two-steps procedure which is motivated by the formula, allows us to perform an independent minimization using less number of parameters. Technically, I have used the MINUIT Fortran-to-C tool through the Inlib library provided by G. Barrand[1]. After a guess of initial parameter values, a χ^2 minimization is performed by the MINImize routine. I have left for future work to perform simultaneously fit in 2D, cf. (t, ν). Note that the resulting χ^2 minimum values have no meaning as the errors are not yet mastered and the description of the beam function is too crude.

On Figure 2 is presented an example of the output fit which intends to show that the formula Eq. 3 and Eq. 4 are quite adapted. In the following sections are investigated the phenomenological parameter values extracted from such fit.

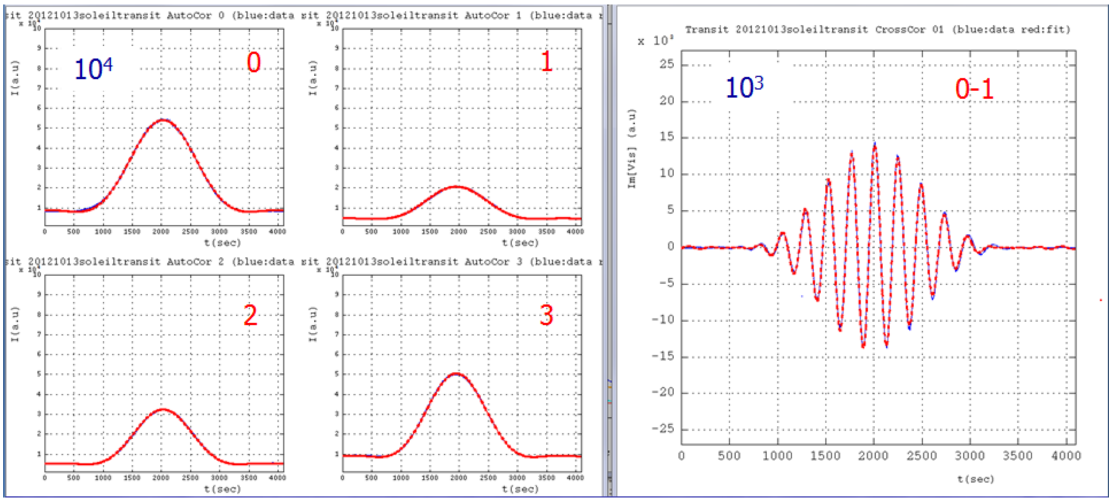

Figure 2 Example of fit of the auto-correlations and a cross-correlation.

3.1 *Auto-correlations*

The Figure 3 shows the noise parameters of the auto-correlations. They are directly related to the analog gains. The oscillations have been confirmed on test bench analysis and a solution is under investigation to reduce the oscillations[2].

[1] Web link to Inlib: http://inexlib.lal.in2p3.fr/ ; for MINUIT have a look at http://wwwasdoc.web.cern.ch/wwwasdoc/minuit/minmain.html

[2] The oscillations have not been suppressed by the replacement of a faulty cable.

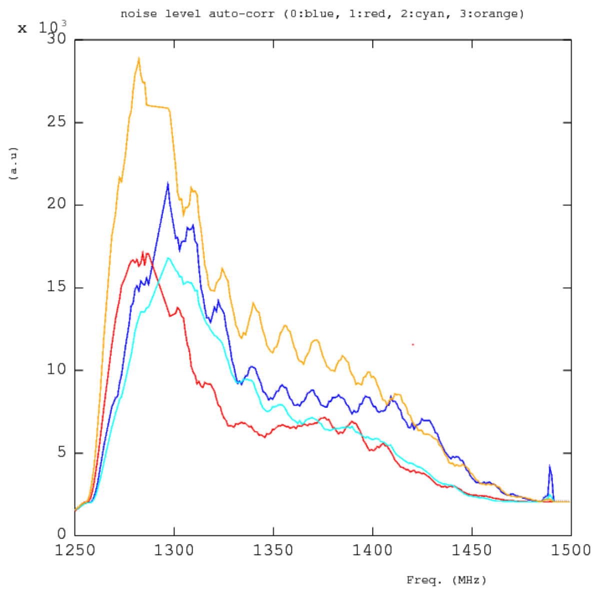

Figure 3 Noise parameter of the auto-correlations.

The effective radii for the 4 channels are shown on Figure 4. It is noticeable that they have quite similar values and a little bit lower to the mechanical radius of the dishes equal to 1.5m. If we take a mean value of 1.3m the aperture antenna gain reduction is of the order of 75%. The wavy behavior is not expected. Notice that horizontal and vertical polarization radii present a sort of opposition phase behavior; and the same orientation polarization in the two feeds are quite similar in amplitude and phase.

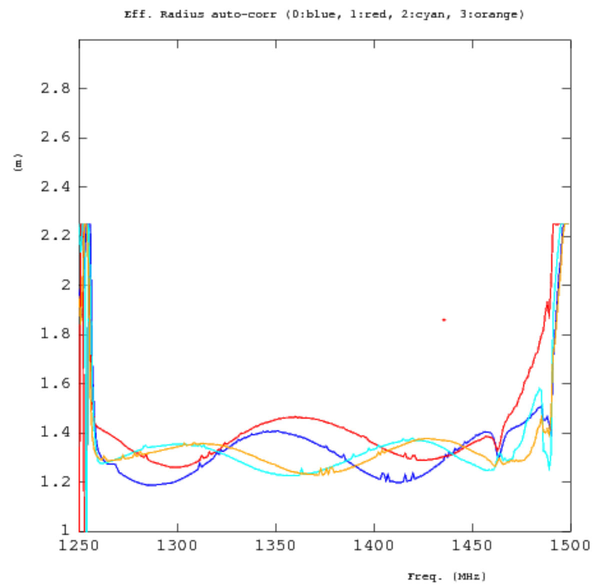

Figure 4 Effective radius for the 4 channels.

Next, it is considered the time of maximum of the auto-correlations. On the edges of the frequency bands the gains are so low that it is not worth to understand the behavior (see also ref. PAON2/09.11.12). But we see clearly a wavy shape of the same order of magnitude considering polarizations of the same feed and remarkably in opposite frequency dependencies. Notice that if the curves of Ch. 0 and 2 are in "phase" with those of Figure 4, but for the curves of Ch. 1 and 3 there is an opposite phase behavior.

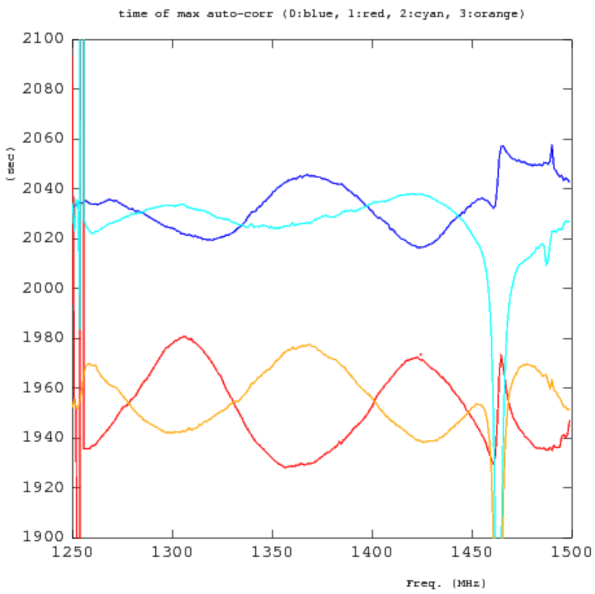

Figure 5 Time of maximum of the auto-correlations.

On Figure 6 are presented the parameter $s_{i,max}$ those squares are the maximum power received at the transit (minus the noise level). If the Sun would have been a perfect calibrator source then these parameters could have be interpreted as a gain in (a.u) translated in K or Jy.

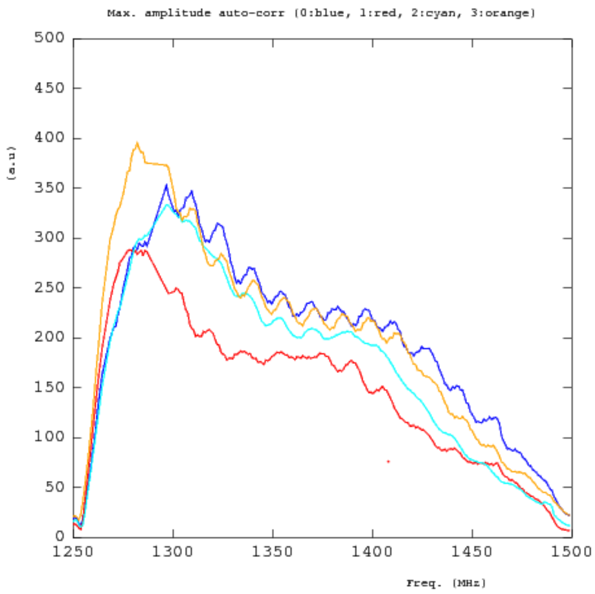

Figure 6 The maximum amplitude of the auto-correlations.

I finish these auto-correlation fits part by an example of correlation coefficients matrix:

	noise	R. eff.	t. max	s. max
noise	1.000	0.257	0.029	–0.555
R. eff.	–	1.000	–0.069	0.181
t. max	–	–	1.000	–0.062
s. max	–	–	–	1.000

We can appreciate the correlation of the noise level with the maximum signal which is quite natural. There are also correlations between the radius and both the noise and the maximum signal. This is also simple to explain because the width of the beam function is directly related to the radius parameter but as it is more or less adjusted at the half maximum, it is influenced by the position and the amplitude of the visibility peak.

3.2 Cross-correlations (imaginary part)

The noise levels of the two cross-correlations are shown on Figure 7. It is clear that these parameters are nothing to do with the auto-correlation ones, and it is noticeable although not explained that the noise of cross-correlation "23" is maximum at ~1300MHz corresponding to maximum of gains[3].

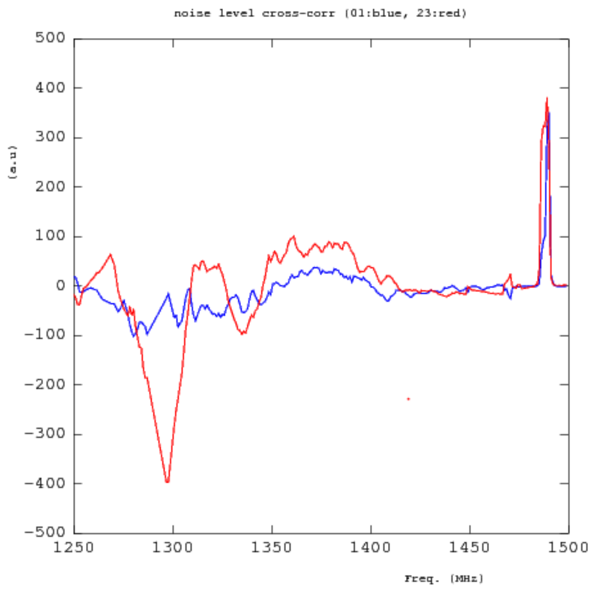

Figure 7 Noise parameters of the cross-correlations.

The time references of the cross-correlations (Figure 8) contrary to the time of maximum of the auto-correlations (Figure 5) are subject to large and almost linear variations with respect to the frequency. Moreover, the two parameters are quite similar and may be replaced by a single parameter in case of simultaneous fit.

[3] This is not due to an extreme sensitivity to guess values.

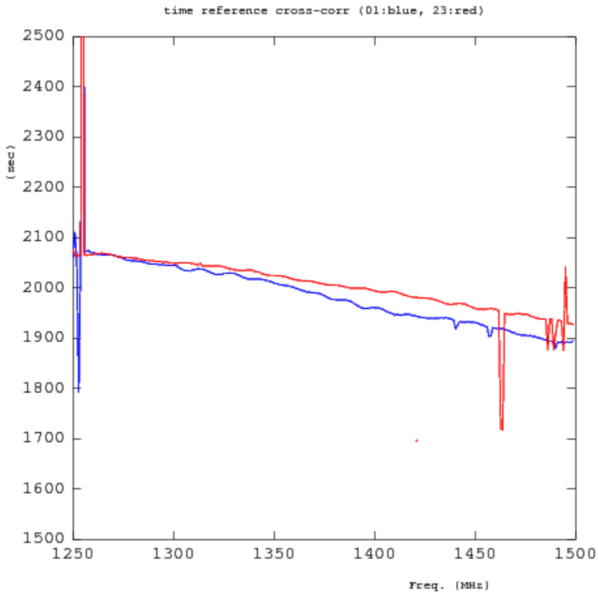

Figure 8 Time reference of the two cross-correlations.

The fringe dilutions parameters are shown on Figure 9. The two parameters are quite smoothly varying with the frequency and are of the order of 0.5-0.6. The Sun extension contributes to this factor. It turns out that the Fourier Transform on the Sun modeled as a uniform illuminating surface gives a contribution of the form:

$$\eta = 2J_1[\pi x]/\pi x$$

with

$$x = b_{WE}\frac{\nu}{c}D_s\cos\Omega(t - t_{\max})$$

which at maximum transit is equal to 0.6 for b_{WE} =12m, D_s= 0.6° at 21cm. The variation along the transit time is completely negligible at that level of precision, so the non-uniformity of the parameters η may be due to other effects non taken into account in the very simplified model of the Sun.

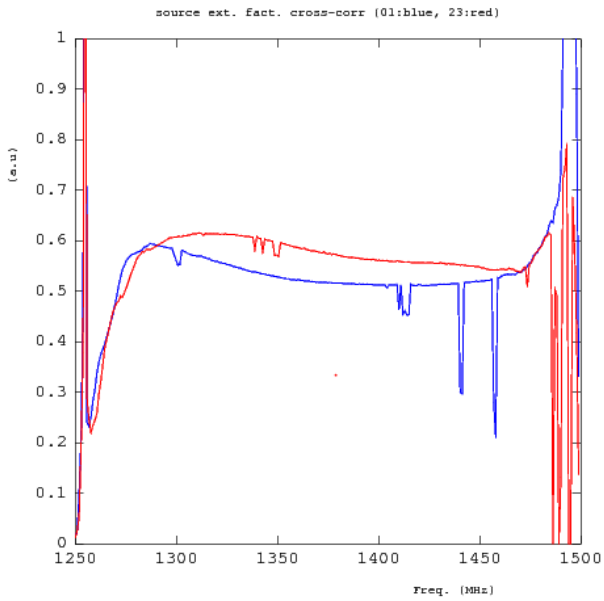

Figure 9 Fringe dilution parameters for both cross-correlations.

The West-East baseline parameters evolutions are shown on Figure 10. They are varying close to the expect 12m length. No modifications of previous results have been raised when the baseline was fixed to a unique constant value.

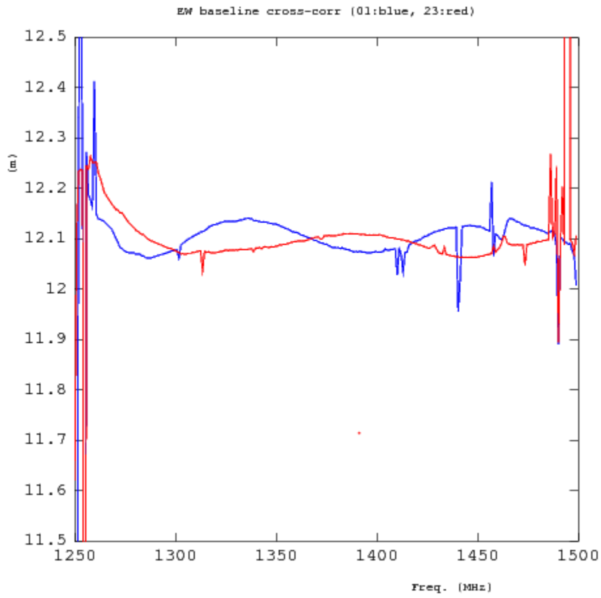

Figure 10 The EW baseline parameters.

Finally, I present a typical correlation coefficient matrix of the free parameters:

	noise	t. ref.	η	b_{EW}
noise	1.000	$<10^{-3}$	$<10^{-3}$	–0.002
t. ref.	–	1.000	–0.286	–0.122
η	–	–	1.000	–0.001
b_{EW}	–	–	–	1.000

The noise parameter is essentially uncorrelated to the other parameters, especially η certainly due to the symmetry of the fringes with respect to the level of noise. The time reference which in fact is the trigger of the zero crossing of the fringes at transit is correlated to the fringes spacing governed by b_{EW} and the amplitude of the fringes scaled by η.

4 Summary & outlook

In this MEMO, a set of formula has been presented and used to describe the auto-correlations and the main cross-correlations visibilities time evolution during bright source transit[4]. It turns out that they are quite suited in the context of bright source. For the Sun which has an extension of the same order of magnitude of the dish beam, the addition of a dilution parameter allows the formula to remain adapted.

The extraction of phenomenological parameters has shown that the mechanical lengths (radius, baseline) are quite well retrieved. Moreover, in the case of the dish radius the smaller value observed (1.3m against 1.5m) may be a contribution to the global gain of the dish. Although, the wavy dependence of the radii with respect to the frequency with an opposite behavior for the horizontal and

[4] Cf. no background/foreground contributions have been introduced.

the vertical polarizations is not yet explained. The wavy behaviors of the time of maximum values of the auto-correlations are also not yet explained. Finally, the time of the zero crossing of the cross-correlations presents a linear dependence with respect to the frequency.

It would be interesting to use the same parametrization on a bright and narrow source transit to see for instance if the η parameters tend to be close to unity. Also improvement of the beam function would be interesting to introduce to better fit the side lobes. But in this purpose, a model of geometrical imperfections on the feed positioning should be developed too, and this could be a quite complicated task. And probably we can envisage a 2D fit with a parametrization of the frequency dependence shown in the previous sections, but it might be useful before starting that task, to have an understanding of such behavior (at least it does not come from fit bias as another minimize have been used with different starting values and so on).

Finally, I would like to point out that the formula Eq. 4 are not adapted to model the other cross-correlations time evolution. For instance, let us take the visibilities between polarizations West Vertical and East Horizontal (03) and between polarizations West Horizontal and East Vertical (21)[5]. At ~1350MHz one gets the following time evolutions:

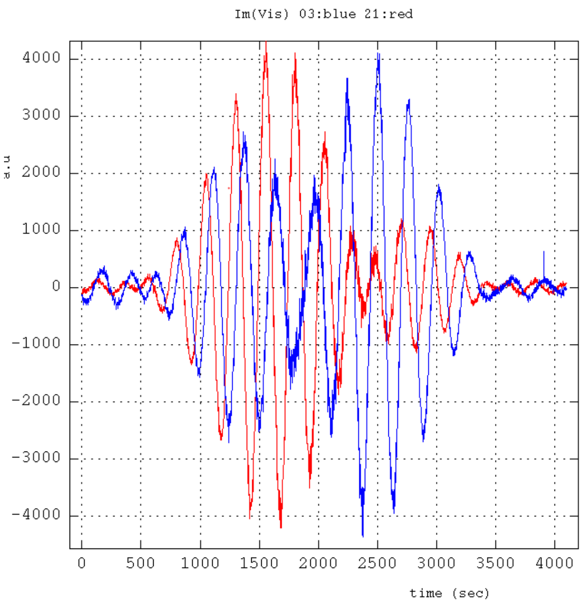

Figure 11 Evolution of WV-EH (blue) and WH-EV (red) visibilities.

These visibilities in principal are supposed to 0; if one considers the tilt of the East horn is tilt by 4° then the amplitude of these visibilities may be of the order of (see Figure 6);

$$s_{max,0}\, s_{max,3} \text{ x } \sin 4° \sim 250^2 \text{ x } 0.07 \sim 4400 \text{ a.u}$$

This is of the right order of magnitude, but Figure 11 shows a beat phenomenon which is not understood and not included in Eq. 4.

[5] What is computed is the « 12 » visibility but to keep West polar versus East polar we have applied a minus sign for the imaginary part.