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Determining the sign of h-rec with the photon calibrator

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1 Introduction

The definition of h has been set in the note [1]:

$$h = \frac{L_x - L_y}{L} \quad (1)$$

In the Virgo interferometer, L_x and L_y are the lengths of the north and west arms respectively, and L their nominal length of 3 km.

The photon calibrator set on the input mirror of the x-arm (NI mirror) has been used to measure whether the Virgo reconstructed h is proportional to $L_x - L_y$ or to $L_y - L_x$, i.e. to check the sign of h.

2 The photon calibrator (pcal) setup and data

2.1 The setup

The Virgo x-arm pcal is set inside the x-cavity. The laser beam hits the input mirror of the cavity from the inside of the cavity as shown in the Fig. 1. When the laser power increases, the force on the input mirror tends to increase the length of the x-cavity $L - x$.

The power of the pcal laser beam is measured through a photodiode located on the pcal injection bench. The output channel is called V1 : Ca_NI_ADC. The measured photodiode voltage increases when the laser power increases as shown in the Fig. 2. The photodiode readout thus does not add a π phase offset.

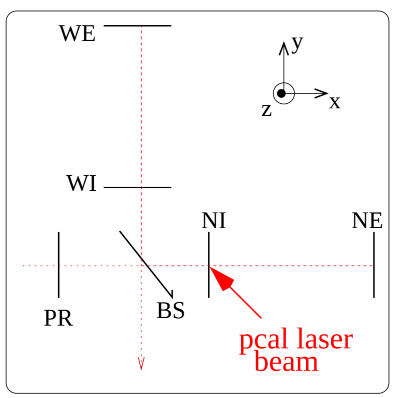

Figure 1: ***x-arm photon calibrator setup.*** *The pcal beam is directed toward the input x-arm mirror, from the interior of the Fabry-Perot cavity.*

2.2 The data

Specific data were taken on May 16th, 2007 from GPS 863374542 to 863374845. The x-arm pcal was used to move the x-arm input mirror of Virgo when it was locked (step 12). Three lines at 38, 118 and 328 Hz were injected. The line amplitudes were all set to 0.3 V in the configuration file. Since the laser power is always positive, an offset higher than 3×0.3 V was needed. It was set to 2 V.

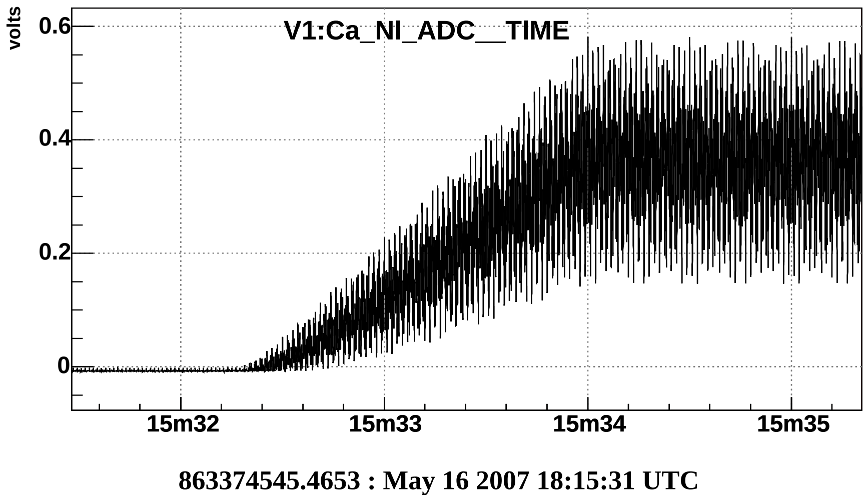

Figure 2: ***Time evolution of*** Ca_NI_ADC ***when the pcal laser is switch on. The laser power is the sum of a DC and three sine signals. A ramp of 2 seconds is applied to increase the laser power smoothly.***

The channel V1 : Ca_NI_ADC was used to monitor the laser power. The h-strain values were reconstructed in the channel V1 : h_20000Hz. Both channels are sampled at 20 kHz.

The FFT of V1 : h_20000Hz during the injection is shown on the Fig. 3 for reference.

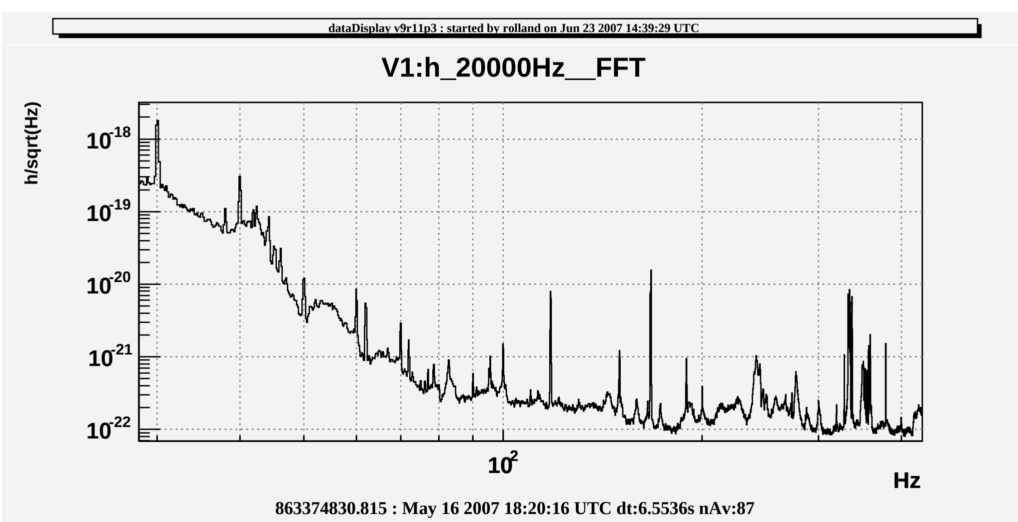

Figure 3: ***FFT of*** V1 : h_20000Hz***.*** *The lines at 38, 118 and 328 Hz have amplitudes of* 1×10^{-19}, 8×10^{-21} *and* 1×10^{-21} *respectively.*

3 Determination of the sign of h

The computatation of the sign of h is based on the following transfert function (TF):

$$\mathrm{TF}\left(\frac{\mathrm{V1:h\_20000Hz}}{\mathrm{V1:Ca\_NI\_ADC}}\right) \tag{2}$$

The TF defined in equation 2 was computed for the specific dataset described above using the reprocessed hrec with version v1r23. Successive time windows of 10 seconds were used. The coherence, gain and phase measured at the three injected line frequencies are given in the table 1. In the h-reconstruction process, the dark fringe signal is filtered through a high-pass Butterworth of 4th order with a cut-off frequency at 10 Hz. The modulus above 10 Hz is not affected by the filter, but the phase is modified. The corrected phase is also given in the table.

Due to the pendulum mechanical response, the mirror movement is in phase opposition with the laser power. Following the definition 1, the phase of the Butterworth-corrected TF should then be $-\pi$. The three measurements are around $-\pi$, within 10°. It means that h **is proportionnal to** $L_x - L_y$, according to the definition.

We note that the sign of h has been modified in the reconstruction code to fullfill the definition on the June, 3rd 2007 (GPS 864900600), from the hrec version v1r20. The previous online hrec version v1r19 had the opposite sign.

3.1 Further data analysis

3.1.1 Variation of the modulus as function frequency

The TF modulus, corrected from the pendulum mechanical response, is given in the table 1. The frequency dependence of the actuators being taken into account in the reconstruction, the modulus should be independent of the frequency above 40 Hz (below, the marionnetta effect is not yet taken into account). The moduli at the three measured frequencies are flat within 10%. This gives an estimation of the error on the shape of the reconstructed h-strain signal. More frequencies have to be measured in order to estimate this error on a larger range.

Frequency (Hz)	$\mathrm{TF}(\frac{\mathrm{V1:h\_20000Hz}}{\mathrm{V1:Ca\_NI\_ADC}})$ Coherence	Modulus (10^{-23} adc^{-1})	Phase (rad)	Corrected Phase (rad)	Corrected modulus (10^{-19} adc^{-1})
38	99.9%	25.8 ± 0.14	-2.542 ± 0.006	-3.232	3.73 ± 0.02
118	99.5%	2.41 ± 0.03	-2.882 ± 0.014	-3.091	3.34 ± 0.04
328	99.0%	0.34 ± 0.01	-3.256 ± 0.020	-3.296	3.66 ± 0.10

Table 1: ***Measured values of the transfert function from*** V1 : Ca_NI_ADC ***to*** h ***sampled at 20 kHz****. The values are given at the three frequencies injected through the pcal. The phase corrected from the Butterworth filter is given. The modulus corrected from the pendulum mechanical response is given.*

3.1.2 Variation of the phase as function frequency

The phase of this TF is defined as the difference between the phases of h and V1 : Ca_NI_ADC. Both can be estimated as:

$$\phi(h) = \phi_0 + \phi_{\text{laser}} + \phi_{\text{pendulum}} \tag{3}$$
$$\phi(\text{NI\_ADC}) = \phi_{\text{laser}} + \phi_{\text{delay}} \tag{4}$$

where:

- ϕ_0 is an unknown phase we are searching for,
- ϕ_{laser} is the phase of the laser input beam,
- ϕ_{pendulum} is the phase of the pendulum mechanical response, which is $-\pi$ for the injected frequencies, much higher than 0.6 Hz.
- ϕ_{delay} is the phase of an hypotetic delay t_d: $\phi_{\text{delay}}(f) = 2\pi \times t_d \times f$. The delay of 1.7 ms from the readout electronics of V1 : Ca_NI_ADC is compensated in the DAQ and should not be visible.

Since the injected frequencies are rather low, no other effect from the readout electronics filters is foreseen on the phase.

The phase of the measured TF can then be deduced:

$$\phi(h) - \phi(\text{NI\_ADC}) = \phi_0 - \pi + \phi_{\text{delay}} \tag{5}$$
$$\phi(h) - \phi(\text{NI\_ADC}) + \pi = \phi_0 + 2\pi \times t_d \times f \tag{6}$$
$$\tag{7}$$

The phase of the measured TF has thus been corrected for π. The corrected phase is plotted as function of the frequency in the Fig. 4. The data point at 38 Hz is at the edge of the validity domain of hrec and its phase might be affected by the uncalibrated marionnetta response.

The three points are close to 0 within 10°. No time delay is visible as foreseen. It indicates that the error on the phase in the reconstruction is of the order of 10°. More data are necessary to estimate the error on a larger frequency domain. However, the phase in the h-strain channels is not corrected for the Butterworth filter yet. Its effect is thus visible below $\sim$ 50 Hz.

4 Conclusion

The Virgo x-arm photon calibrator has been used to compute the sign of the reconstructed h-strain. It was shown that the sign of the reprocessed data fullfill the definition (from hrec version v1r20).

For analysis using the online h-strain of Virgo interferometer up to June, 3rd 2007 (GPS 864900600, hrec version v1r19), the Virgo h-strain must be multiplied by -1. For the online h-strain reconstructed after this date (hrec version v1r20) and the reprocessed data, the sign should not be changed.

The photon calibrator injections allow to estimate the error of the reconstruction on the phase and on the shape of the modulus. The current preliminary estimations are an error of $\pm 10°$ on the phase, and a shape of the reconstructed modulus flat within 10%.

Further measurements using the photon calibrator during VSR1 will be performed in order to monitor the sign of h. More frequencies are needed in order to estimate the phase and modulus errors in a larger frequency range.

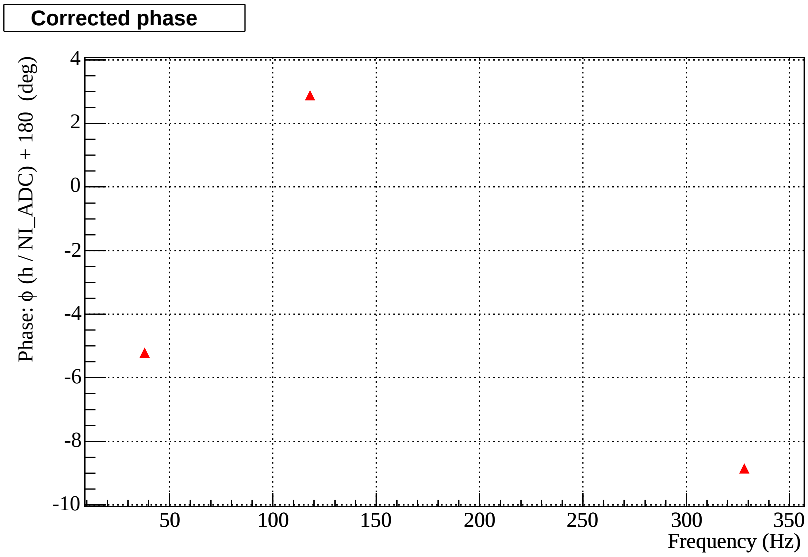

Figure 4: ***Phase as function of frequency, corrected from the pendulum response.*** *The triangles show the measured data points. The dashed line is the fit by a line with parameters p0 and p1.*

References

[1] http://touro.ligo-la.caltech.edu/ irish/Work/Calibration/SignConvention.pdf