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Preliminary VSR4 calibration (June 2011)

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1 Introduction

This note gives the status of the Virgo calibration in June 2011 for the start of the Virgo 4th Science Run, VSR4. The calibration data were taken during two weeks before the run, from May 19th to May 21st 2011[1].

The methods are the same as described in [1], [2] and [3]. Between the end of VSR3 and the start of VSR4, the modifications of the interferometer (ITF) are not expected to modify the calibration (timing and actuation). A modification in the dark fringe sensing is expected to be transparent for calibration:

1. use of shaping filter (nominally 2 Hz − −12 Hz, 2nd order) in the readout of the dark fringe photodiodes, channels Pr_B1_d2, 3_ACp. The reverse shaping filters have been implemented in *Pr*.

During VSR3, the mirror actuation was used in the so-called *Low-Noise 1* (LN1) mode. It might be switched to *Low-Noise 2* (LN2) mode if actuation DAC noise appears to limit the sensitivity, which is not the case presently. However, the NE and WE mirror actuation have been calibrated both in LN1 and in LN2.

2 Dark fringe timing and sensing

A synoptic of the general sensing of the dark fringe channels is shown in the figure 1 of [2].

2.1 Pr_B1_ACp and Pr_B1p channels

The sensing and timing of the raw channels $Pr\_B1\_d\{2,3\}\_ACp$ have been studied as described in [2].

The ramped 1 PPS signal from the GPS receiver sampled in the same ADC board as the photodiodes signals $Pr\_B1\_d\{2,3,4,5\}\_ACp$ and $Pr\_B1p\_d\{2,3,4,5\_DC,ACp,ACq\}$ is stored in the channel $Ti\_1PPS\_GPSMaster$ at 20 kHz to monitor the timing. The delay between the start of the frame and the start of the ramp is computed online and stored in $Ti\_1PPS\_GPSMaster\_t0$. No significant change was found since VSR3: the measured value of $Ti\_1PPS\_GPSMaster\_t0$ is 44.98 ± 0.01 µs.

As a further check, the ramp signal has been sampled at 800 kHz in the channel $Ti\_1PPS\_GPSMaster\_800KHz$ during few minutes[2]. The measured delay between the start of the frame and the 1 PPS signal was −113.6 µs, as during VSR2[3].

[1] Stored in files with calibration period 961000000_999000000.

[2] June 1st 2011, 10h30m to 10h45m UTC

[3] see logbook entry 29521 and figure 4 of [2].

It has been checked that the timing of the combined channel Pr_B1_ACp is the same as the one from the two photodiodes (the TFs $Pr\_B1\_ACp/Pr\_B1\_d\{2,3,4,5\}\_ACp$ have a flat modulus and a flat phase at 0).

To conclude, the timing and sensing of the dark fringe channels did not change since VSR2 and VSR3. The models given in the table 1, p.3 of [5] are still valid for VSR4.

2.2 Shaping filters on $Pr\_B1\_d\{2,3\}\_ACp$

Up to May 2011, the readout of the dark fringe channels $Pr\_B1\_d\{2,3\}\_ACp$ did not use any shaping filter. In the same ADC board, channels with shaping filters [4] have been used from end of May 2011. The reverse shaping filters have been setup in the Pr configuration such that the sum of the two signals, Pr_B1_ACp, does not depend on the channel that is used (flat or shaped).

Preliminary shaping filters measurements had been done at LAPP few years ago. Direct measurements could be done in the data since two channels are stored for each photodiode:

- $Pr\_B1\_d\{2,3\}\_ACp\_flat$ without shaping filter, at 20 kHz (as before),
- $Pr\_B1\_d\{2,3\}\_ACp\_shap$ with shaping filter, at 20 kHz, and before the reverse shaping is applied in Pr.

The TF $Pr\_B1\_d\{2,3\}\_ACp\_shap/Pr\_B1\_d\{2,3\}\_ACp\_flat$ is thus a measurement of the shaping filter (the digital Butterworth filter being the same for both channels). It is precisely measured with the ITF locked in step 12, during wide band noise injections, in particular during the Virgo TF measurements. Measurements from May 31st [5] have been used to fit the shaping filters and update the Pr configuration before VSR4 [6]. A monitoring of the shaping filters stability will be done using the weekly measurements of the Virgo TF.

[4] Nominally second order filters, with zero at 2 Hz, pole at 12 Hz, Qs of 0.5
[5] GPS 990890828, 5 minutes.
[6] See logbook entries 29510 and 29518

3 Calibration of the mirror actuation

The mirror actuation is defined as the TF (with modulus in m/V) from the correction signal to the induced mirror motion. The time reference is the GPS time.

In the plots that are shown, the actuation is corrected for the mechanical model of the pendulum, defined as a 2nd order low-pass filters with $f_0 = 0.6\,\mathrm{Hz}$ and $Q = 1000$.

3.1 Mirror actuation in LN1 mode

Since no change is expected between VSR3 and VSR4 mirror actuation in LN1 mode, the pre-VSR4 measurements have been compared to the VSR3 measurements. The absence of significant time variation is shown in this section. As a consequence, in LN1 mode, the actuation model computed for VSR3 [5] can be used for VSR4 online processes. Parameterizations have been extracted for the NE and WE mirror actuation in LN2 mode.

3.1.1 Stability of the mirror actuation in LN1 mode

As usual, the mirror actuation in LN1 mode is done in two measurement steps:

- measurement of the mirror actuation in HP mode, extracted from data in free swinging Michelson,
- measurement of the LN1/HP ratio of the actuation, extracted from the actuation current response,
- extraction of the mirror actuation in LN1 mode from the two former results.

Some differences arise with respect to VSR3 datasets:

- the lines around 8 Hz were not injected and the white noise low frequency range increased from 4 Hz to 10 Hz (in order not to excite the 8 Hz θ_z oscilation of the end mirror payloads).
- the LN/HP measurements were done using mainly lines, instead of mainly white noise during VSR3. This was aimed at being sensitive enough in LN2/HP measurements.

The figures in 3.1.2 show the time variation of both type of measurements at some frequencies for the different coils, from July 2010 to May 2011.

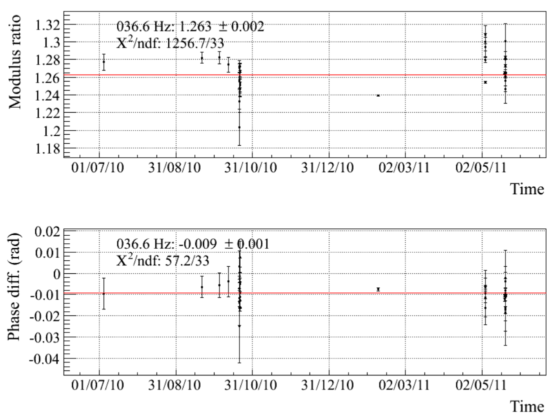
All measurements show very good stability, within $\sim 1\%$, except for some:

- BS mirror actuation in HP mode (free Michelson) tends to have a gain lower by $\sim 1.5\%$ wrt VSR3.

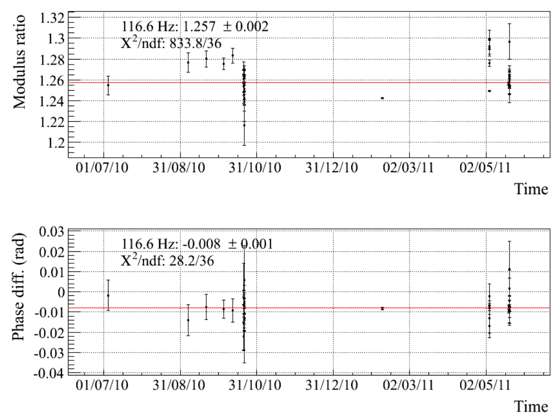
- BS,coilUL, BS,coilUR, NE,coilR and WE,coilD have gains different by few percent when lines or white noise is injected. This was already noticed during VSR3 calibration. Since lines are more often injected in the new datasets, the average value might slightly change, but still within the systematic errors that were estimated in the past.

After the combination of all the measurements from July 2010 to May 2011, the mirror actuation in LN1 has been computed. The parameterizations are the same as the ones from VSR3 within better than 1% in modulus and few mrad or 1 μs in phase and timing. **As a consequence, we conclude that the VSR3 parameterizations can still be used for VSR4 (see tables 3 and 4, p. 10,11 of [5]).**

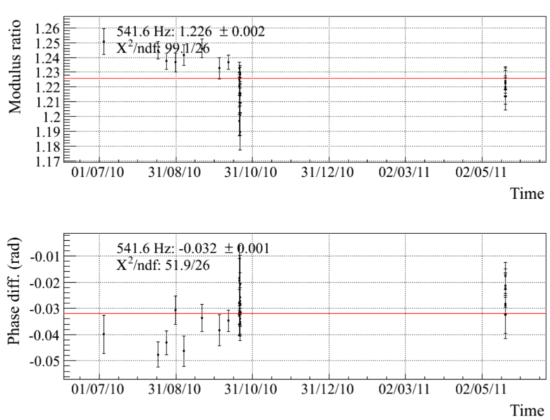
3.1.2 Figures: actuation stability in LN1 mode



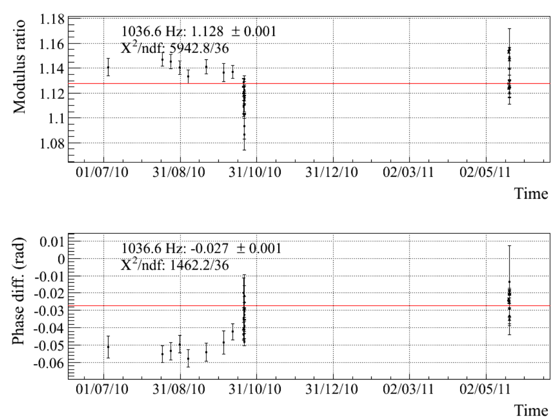
(a) 36.5 Hz



(b) 116.5 Hz

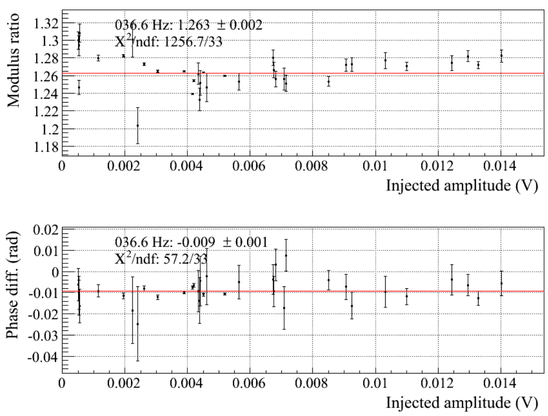


(c) 451.5 Hz

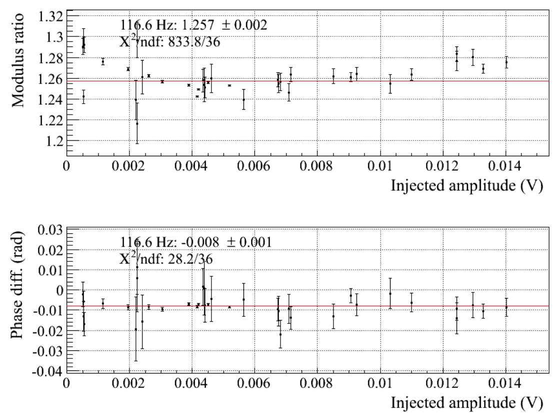


(d) 1036.5 Hz

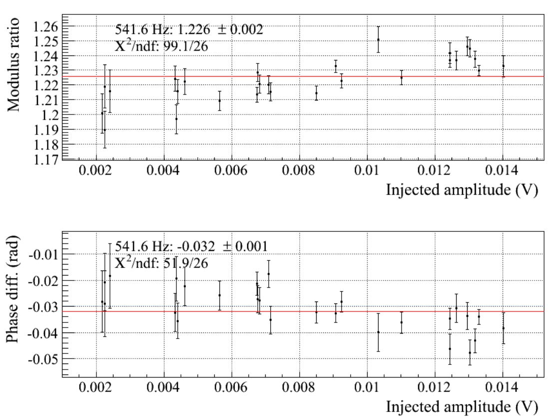
Figure 1: ***Evolution as function of time (June 2010 to May 2011) of the measured actuation TF ratio (LN1/HP) for the up coil of the WE mirror*** *at four different frequencies.*



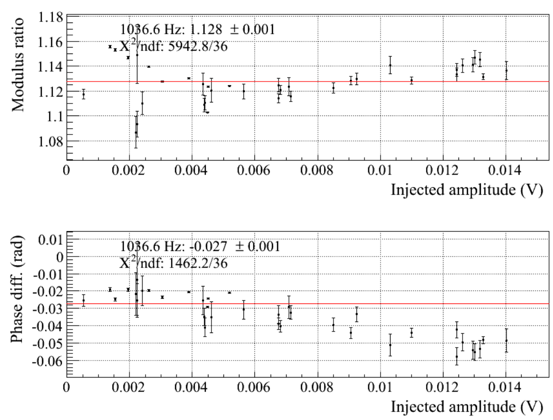
(a) 36.5 Hz



(b) 116.5 Hz

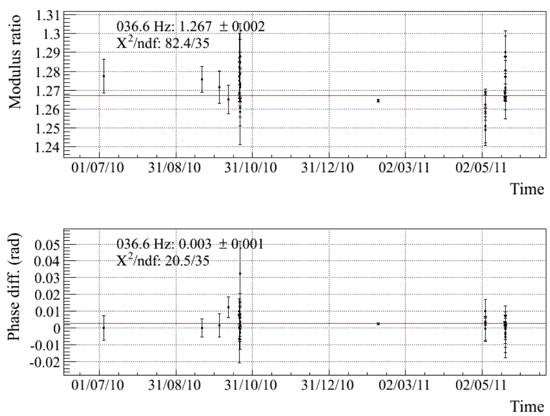


(c) 451.5 Hz

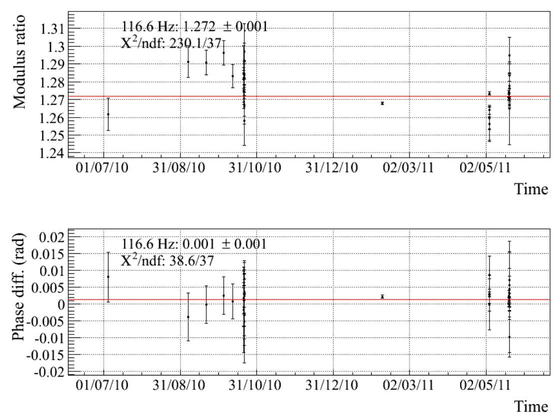


(d) 1036.5 Hz

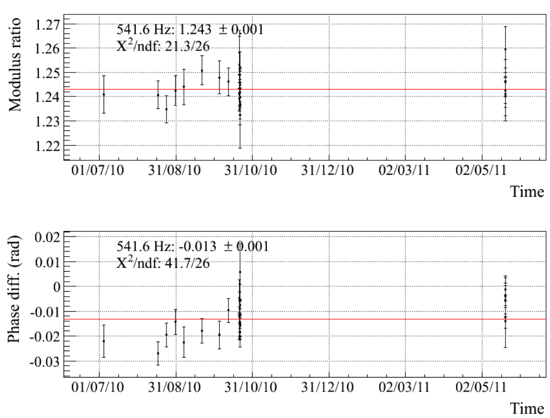
Figure 2: ***Evolution as function of the signal amplitude of the measured actuation TF ratio (LN1/HP) for the up coil of the WE mirror*** *at four different frequencies. The amplitude in the x-axis is the amplitude of* $V1 : Ca\_WE\_RM\_CoilU$ *during the injections in LowNoise mode.*



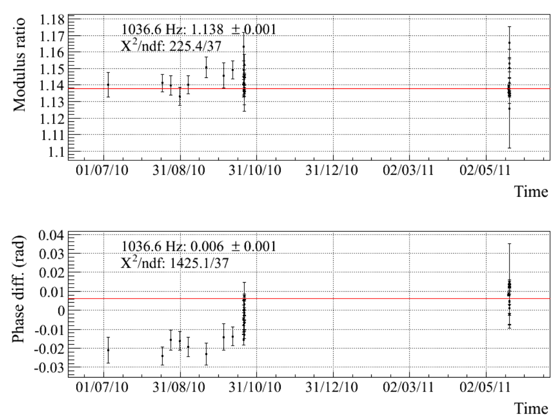
(a) 36.5 Hz



(b) 116.5 Hz

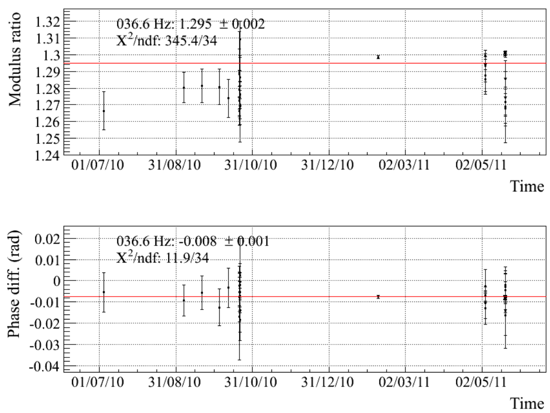


(c) 451.5 Hz

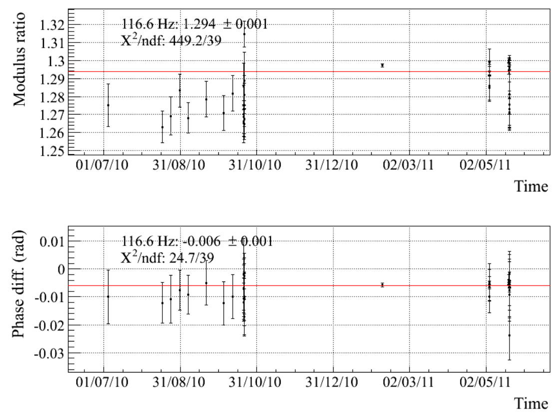


(d) 1036.5 Hz

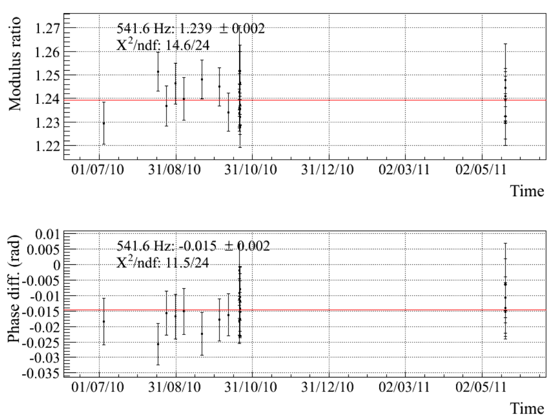
Figure 3: ***Evolution as function of time (June 2010 to May 2011) of the measured actuation TF ratio (LN1/HP) for the down coil of the WE mirror*** *at four different frequencies.*



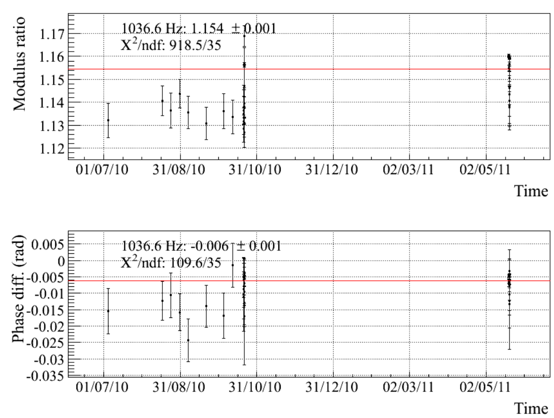
(a) 36.5 Hz



(b) 116.5 Hz

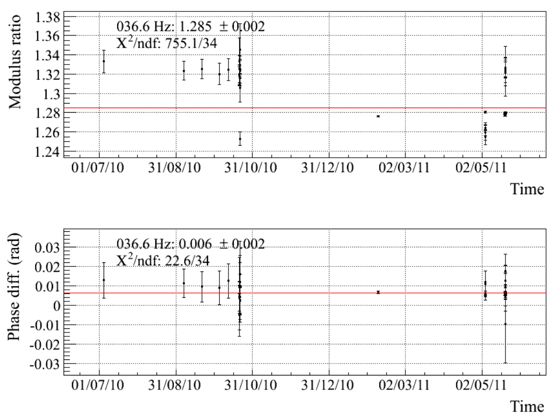


(c) 451.5 Hz

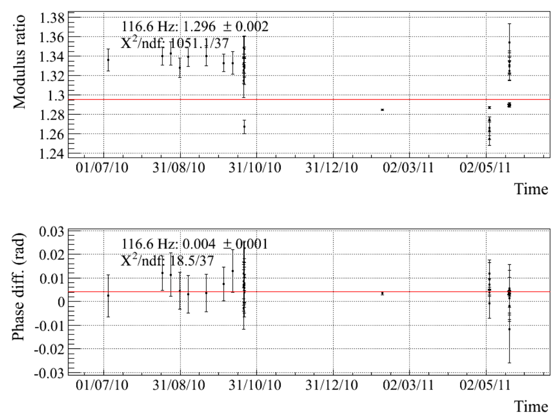


(d) 1036.5 Hz

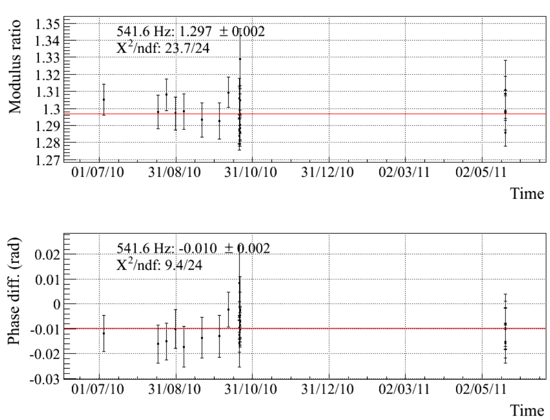
Figure 4: ***Evolution as function of time (June 2010 to May 2011) of the measured actuation TF ratio (LN1/HP) for the left coil of the WE mirror*** *at four different frequencies.*



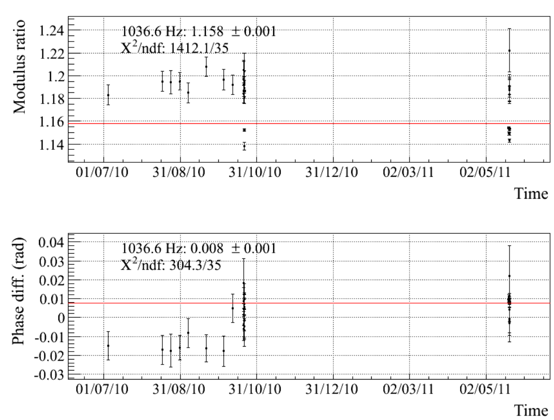
(a) 36.5 Hz



(b) 116.5 Hz

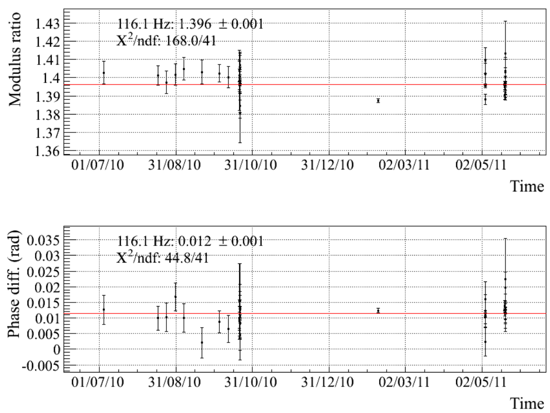


(c) 451.5 Hz

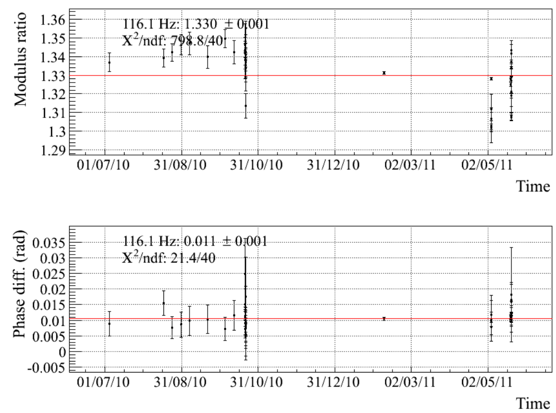


(d) 1036.5 Hz

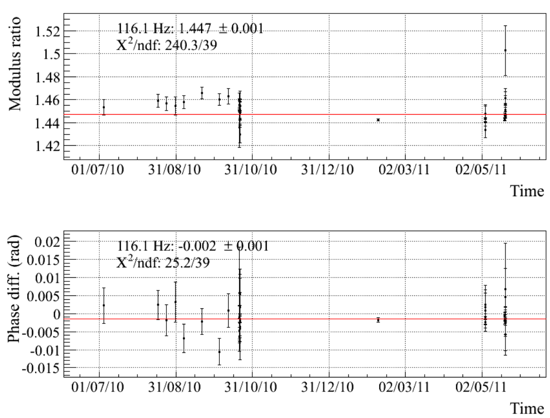
Figure 5: ***Evolution as function of time (June 2010 to May 2011) of the measured actuation TF ratio (LN1/HP) for the right coil of the WE mirror*** *at four different frequencies.*



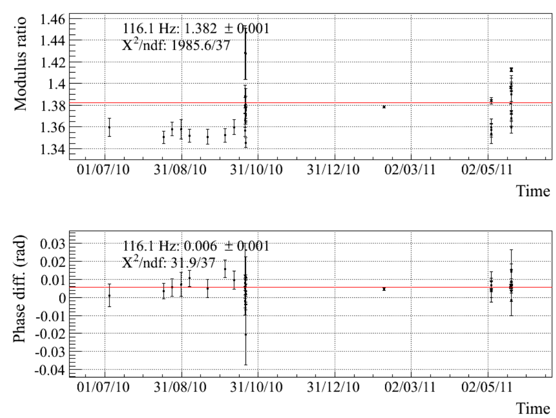
(a) Coil Up, 116.0 Hz



(b) Coil Down, 116.0 Hz

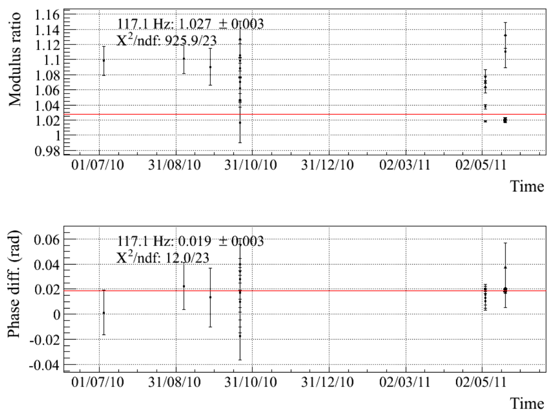


(c) Coil Left, 116.0 Hz

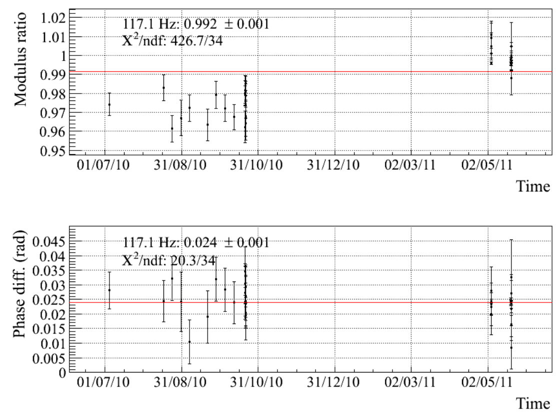


(d) Coil Right, 116.0

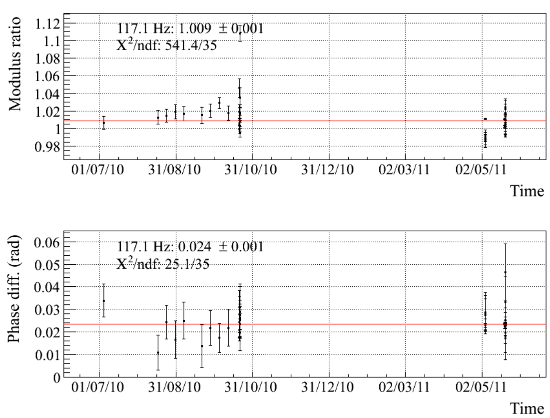
Figure 6: ***Evolution as function of time (June 2010 to May 2011) of the measured actuation TF ratio (LN1/HP) for the four coils of the NE mirror*** *at a fixed frequency.*



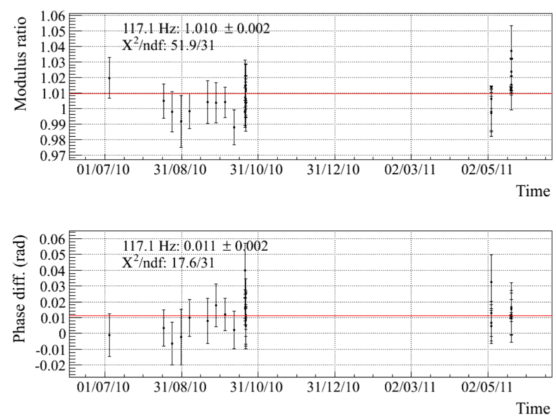
(a) Coil Up-Left, 117.0 Hz



(b) Coil Up-Right, 117.0 Hz



(c) Coil Down-Left, 117.0 Hz



(d) Coil Down-Right, 117.0 Hz

Figure 7: ***Evolution as function of time (June 2010 to May 2011) of the measured actuation TF ratio (LN1/HP) for the four coils of the BS mirror*** *at a fixed frequency.*

3.2 Mirror actuation in LN2 mode

The mirror actuation in LN2 mode is done in two measurement steps, as for the LN1 measurement:

- measurement of the mirror actuation in HP mode, extracted from data in free swinging Michelson,
- measurement of the LN2/HP ratio of the actuation, extracted from the actuation current response,
- extraction of the mirror actuation in LN1 mode from the two former results.

The figures in 3.2.2 show the LN2/HP ratio of the actuation as function of the level of the injected noise, as well as the average of the all the pre-VSR4 data. The behaviour of all coils is correct, except for NE, coilL, which seems to have a LN2 response being half of the expected one. However, during VSR4, even if LN2 is used, no blind injections are planned: the left and right coils of NE will thus not be used for injections.

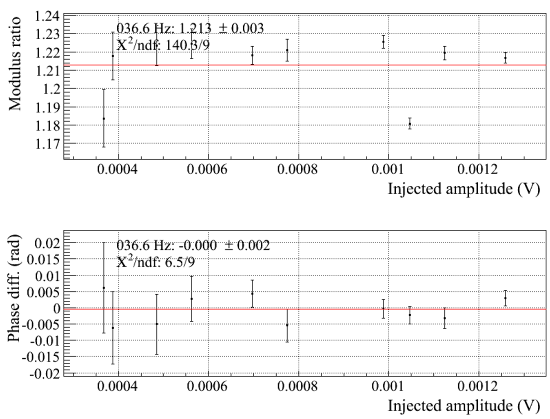
The last figures (12 to 14) show the measured mirror actuation response in LN2 mode along with the fitted parameterization and the residuals. The parameterizations are given in the table 1.

3.2.1 Tables: actuation in LN2 mode

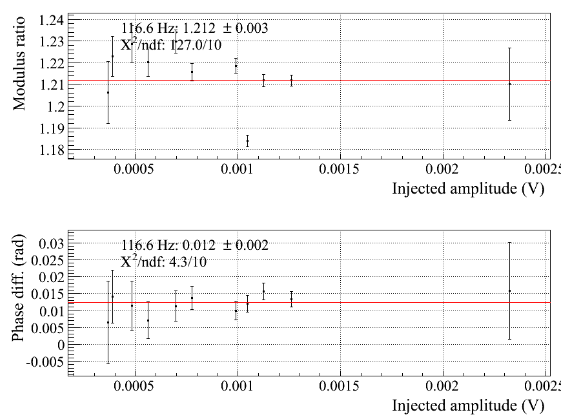
		WE, U-D coils	NE, U-D coils	WE, L-R coils
LN2	Gain (μm/V)	18.656 ± 0.01	20.847 ± 0.014	18.755 ± 0.01
	Raw delay (μs)	(398.8 ± 1.6)	(411.8 ± 1.2)	(585.2 ± 1.7)
	Delay (μs)	249.5 ± 1.6	262.5 ± 1.2	635.9 ± 1.7
	Φ_0 (rad)	0	0	0
	DAC anti-alias filter	See model in table 2, p.10, of [5]		-
	Pendulum	One 2nd order low-pass filter: $f_0 = 0.6\,\mathrm{Hz}$, $Q = 1000$		
	χ^2/ndf	89.4/70	71.3/72	1110/74

Table 1: ***WE (U-D coils), NE (U-D coils) and WE (L-R coils) mirror actuation parameterizations in LN2 mode****, The models are valid up to 1.0 kHz. The* χ^2/ndf *of the fits are given. The raw delay is the measured delay that includes the delay from the injection path to the DSP and the delay from the Pr_B1p channels sensing.* **For the U-D coils** *used in the controls and in hrec, the corrected delay takes as reference the correction channel in the DSP (i.e. Sc_WE_zCorr) and does not contain the B1 sensing delay nor the delay for the injection part (raw delay with 100* μs *less for the PrCa to DSP delay and 49.3* μs *less from the dark fringe sensing: delay* $= raw\_delay - 100 - 49.3$ μs*). Applying these TFs to zCorr should enable to estimate the induced motion at absolute GPS time.* **For the L-R coils** *used in the hardware injections, the corrected delay takes as reference the channels sent by the CaInjectors (i.e. Ca_WE_zMirLR) and does not contain the B1 sensing delay (raw delay with 100* μs *more since the hardware injections are done from the CaInjectors and 49.3* μs *less from dark fringe sensing: delay* $= raw\_delay + 100 - 49.3$ μs*). Applying these TFs to Ca_WE_zMirLR channels should enable to estimate the induced motion at absolute GPS time.*

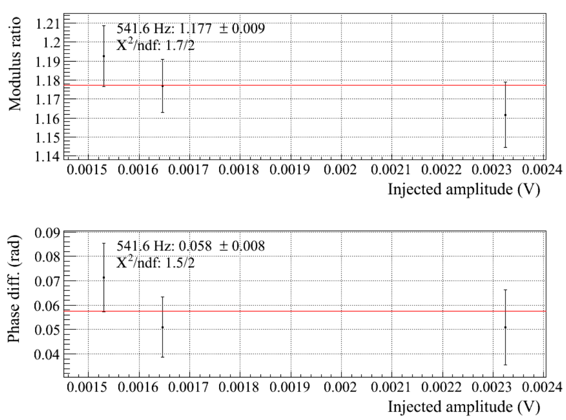
3.2.2 Figures: actuation in LN2 mode



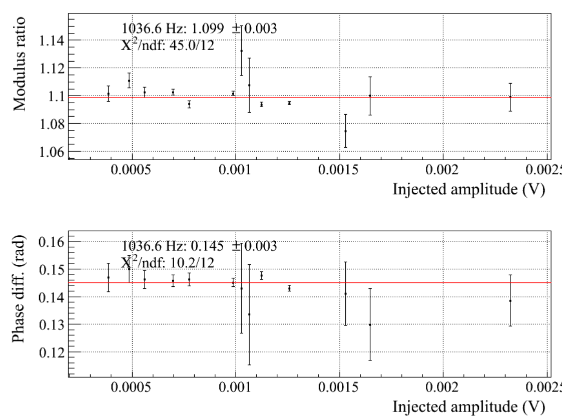
(a) 36.5 Hz



(b) 116.5 Hz

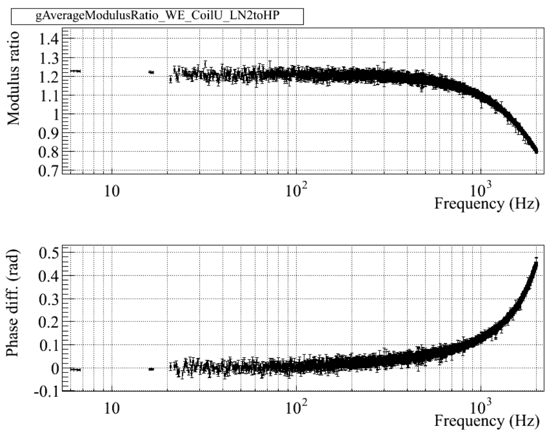


(c) 451.5 Hz

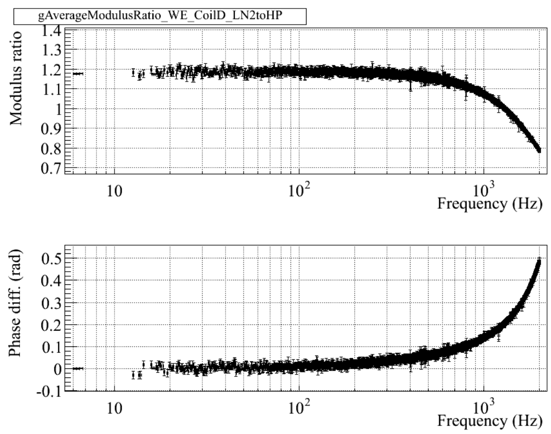


(d) 1036.5 Hz

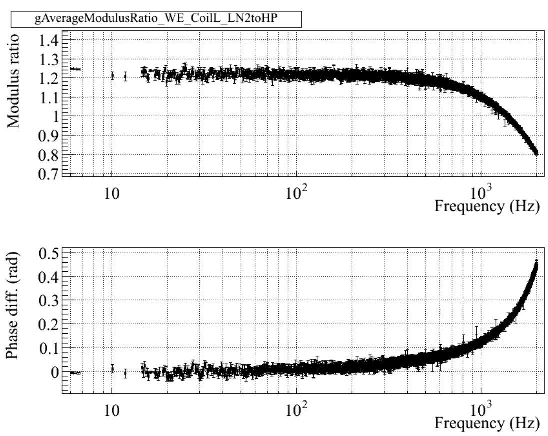
Figure 8: ***Evolution as function of the signal amplitude of the measured actuation TF ratio (LN2/HP) for the up coil of the WE mirror*** *at four different frequencies. The amplitude in the x-axis is the amplitude of $V1 : Ca\_WE\_RM\_CoilU$ during the injections in LowNoise mode.*



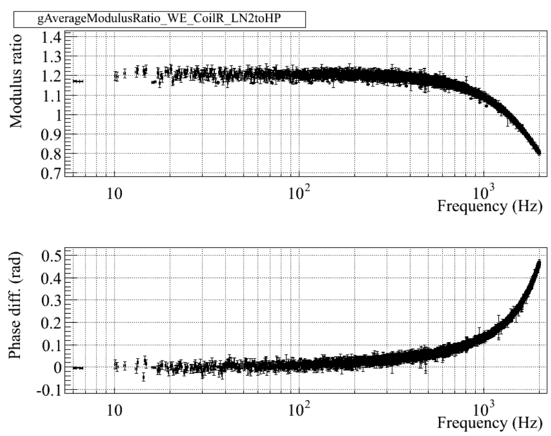
(a) Coil U



(b) Coil D

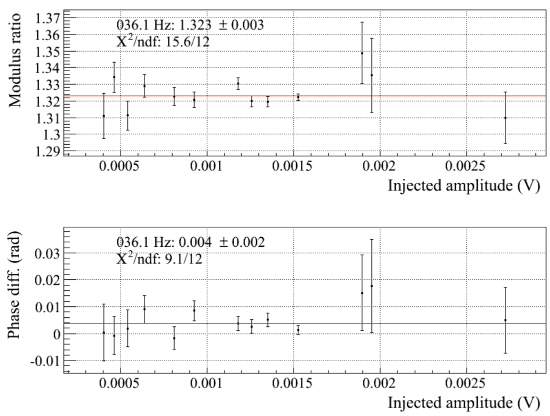


(c) Coil L

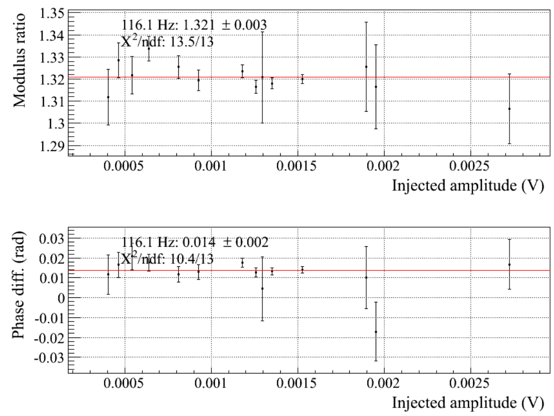


(d) Coil R

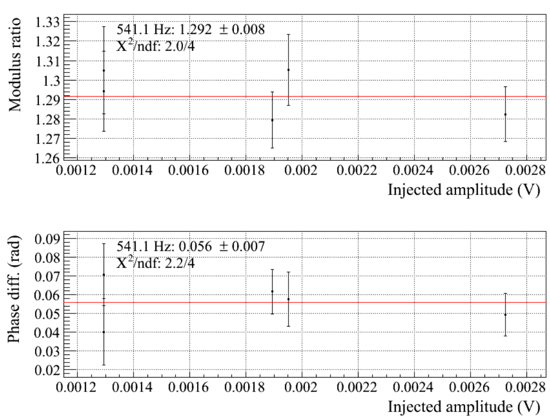
Figure 9: ***Measured actuation TF ratio (LN2/HP) for the four coils of the WE mirror.***



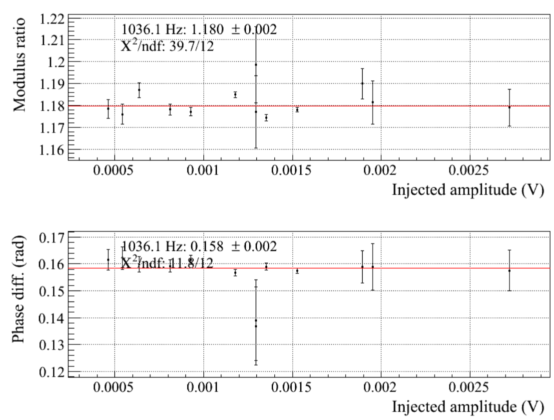
(a) 36.5 Hz



(b) 116.5 Hz

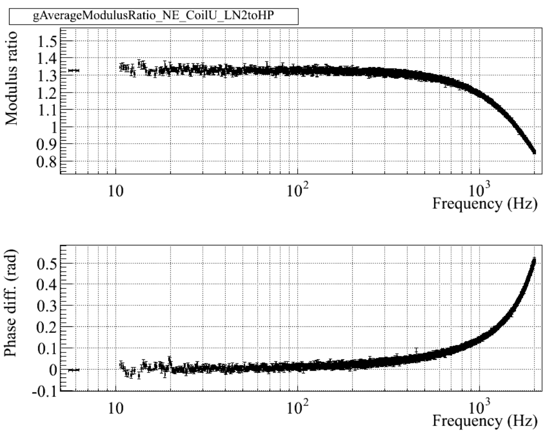


(c) 451.5 Hz

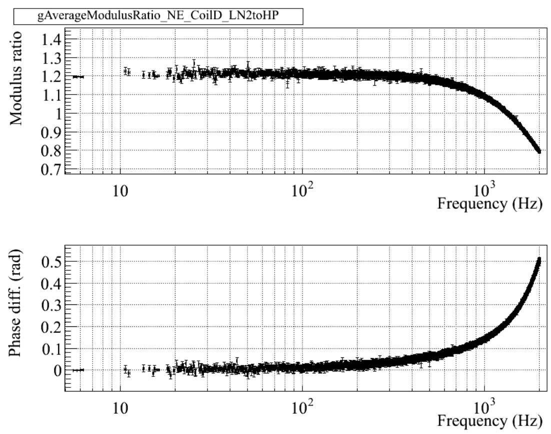


(d) 1036.5 Hz

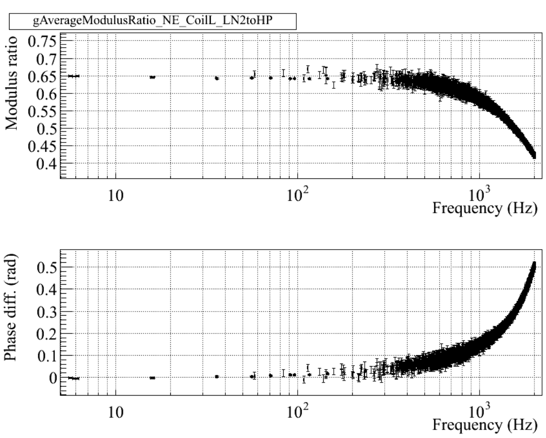
Figure 10: ***Evolution as function of the signal amplitude of the measured actuation TF ratio (LN2/HP) for the up coil of the NE mirror*** *at four different frequencies. The amplitude in the x-axis is the amplitude of* $V1 : Ca\_NE\_RM\_CoilU$ *during the injections in LowNoise mode.*



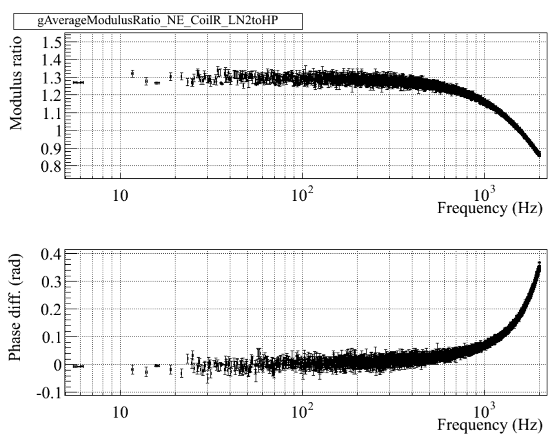
(a) Coil U



(b) Coil D

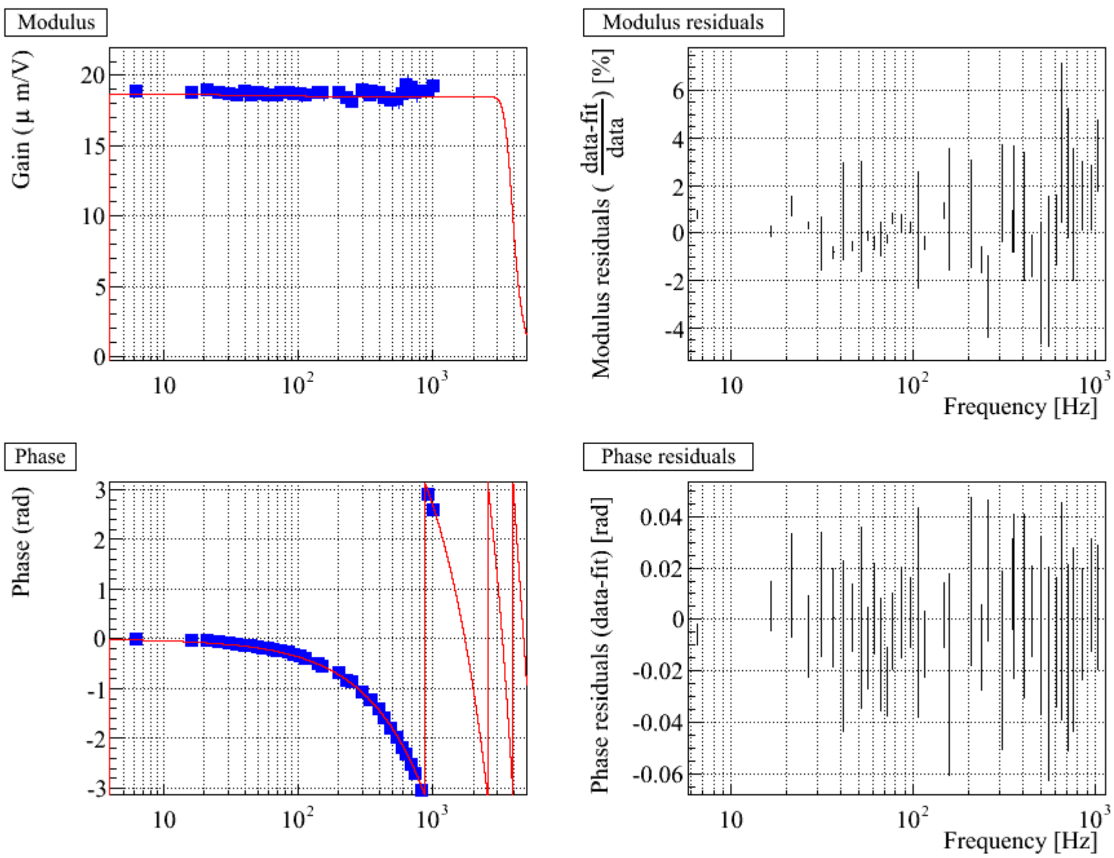


(c) Coil L



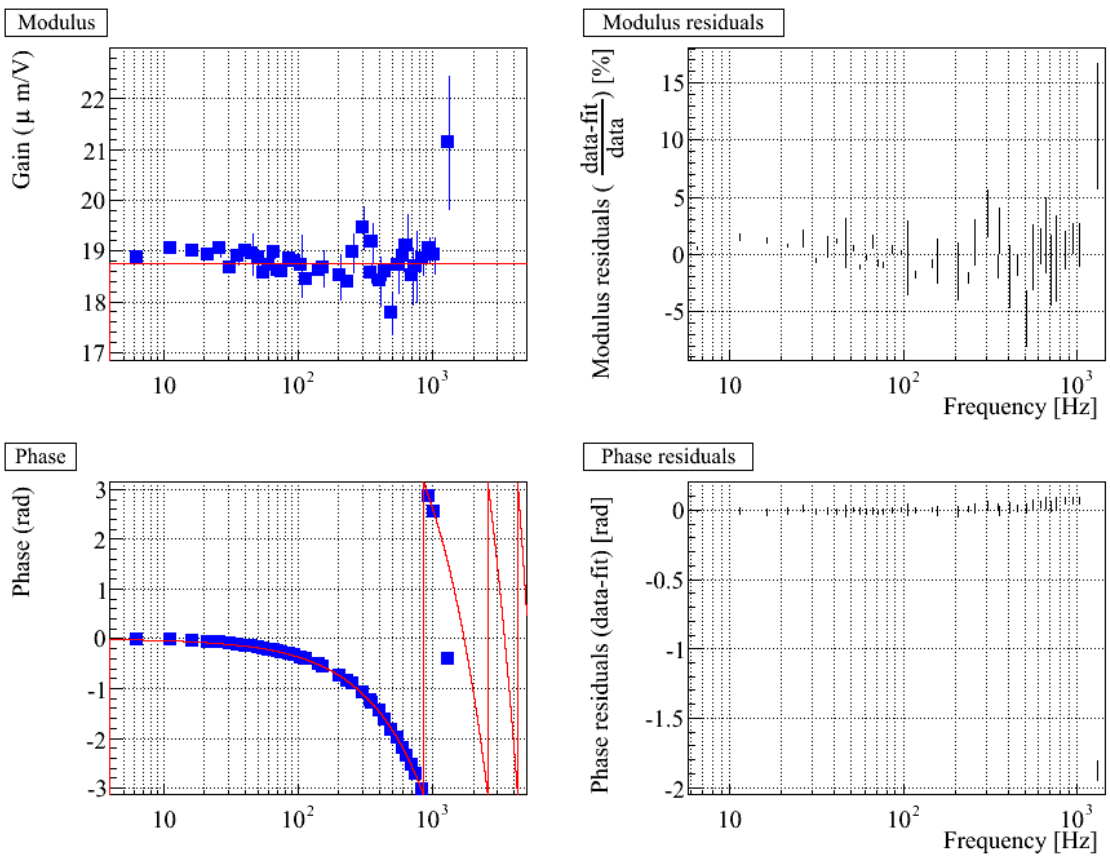
(d) Coil R

Figure 11: ***Measured actuation TF ratio (LN2/HP) for the four coils of the NE mirror.***



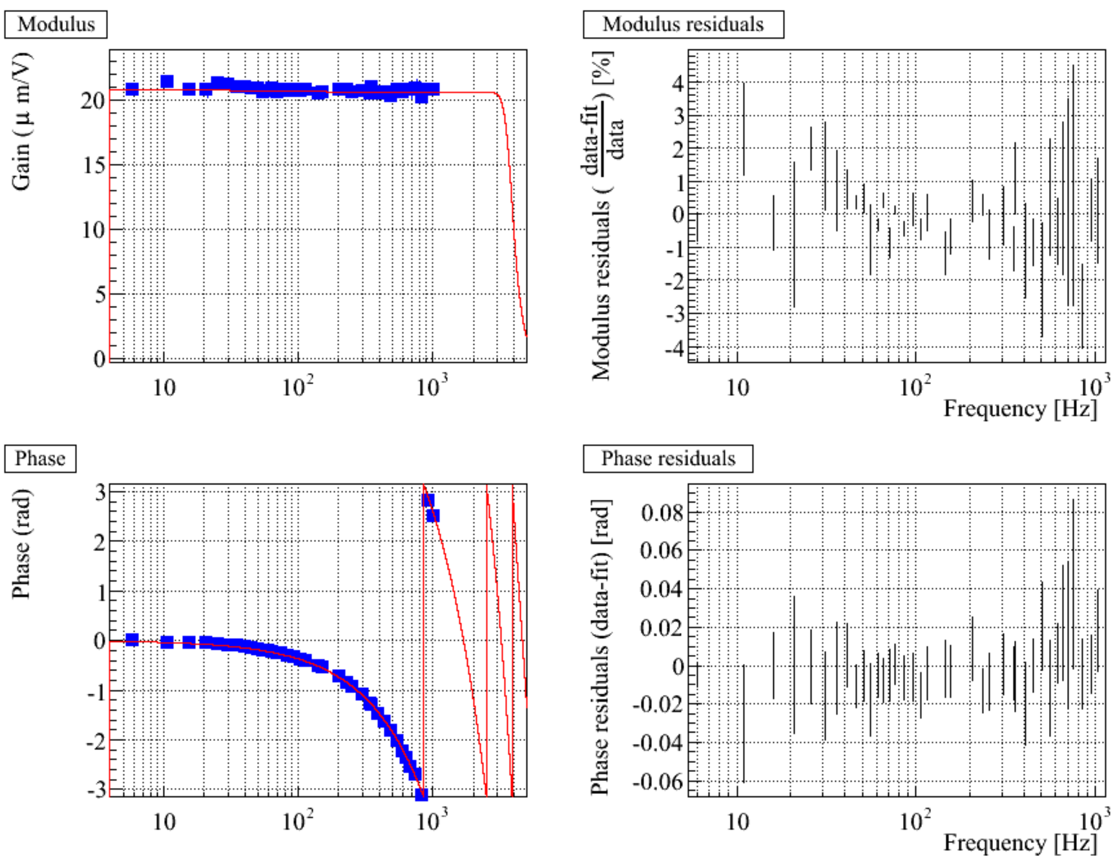
(a) WE, U-D, LN2

Figure 12: ***Measured mirror actuation TF of the WE mirror (U-D coils) in LN2.***



(a) WE, L-R, LN2

Figure 13: ***Measured mirror actuation TF of the WE mirror (L-R coils) in LN2.***



(a) NE, U-D, LN2

Figure 14: ***Measured mirror actuation TF of the NE mirror (U-D coils) in LN2.***

4 Calibration of the marionette actuation

The marionette actuation is defined as the TF (with modulus in m/V) from the correction signal to the induced mirror motion[7] (i.e. Sc_WE, NE_zM). The time reference is the GPS time.

In the plots that are shown, the actuation is corrected for the mechanical model of the pendulum, defined as **two** 2nd order low-pass filters with $f_0 = 0.6\,\mathrm{Hz}$ and $Q = 1000$.

4.1 Time stability of the marionette to mirror actuation ratio

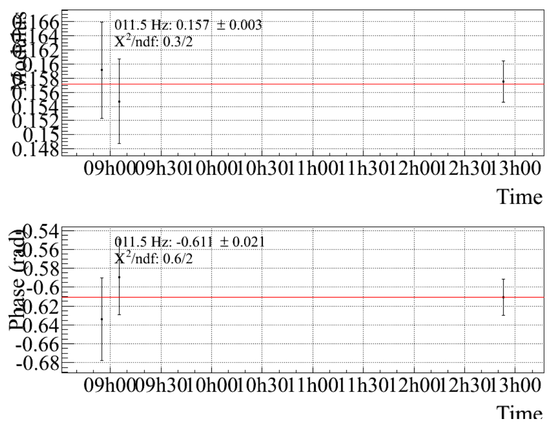
The figures in 4.3 show the time stability of the WE and NE marionette to mirror actuation ratio, at some frequencies, from July 2010 to May 2011. Thanks to a better sensitivity at low frequency, the measurement from May 2011 are better than the one from VSR3. However, no significant time variation is visible.

4.2 Calibration of the WE and NE marionettes

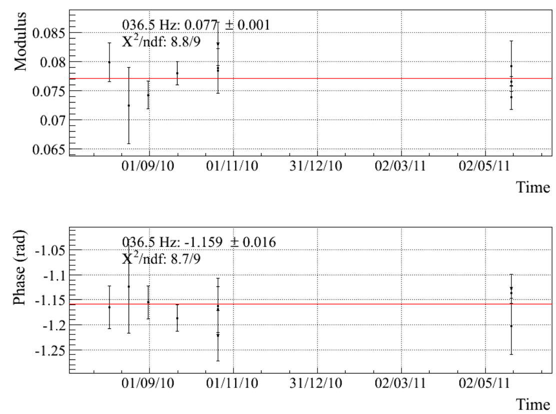
Since both the mirror actuation in LN1 mode and the marionette to mirror actuation ratio have been stable from VSR3 to May 2011, **the VSR3 parameterizations for the marionettes can still be used for VSR4 (see table 6, p.50 of [5]).**

4.3 Figures

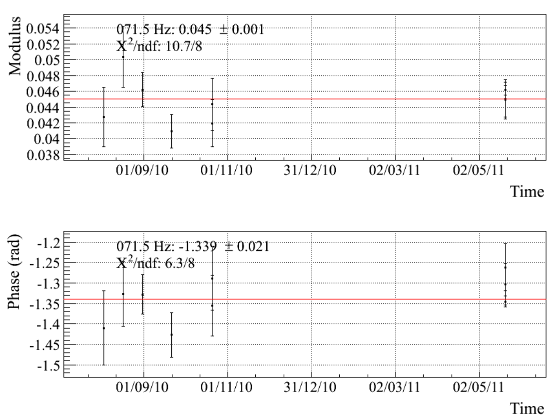
[7] The marionette longitudinal actuation is done through two coils (left and right). Emphasis filters are set in the DSP for both coil channels in order to compensate for de-emphasis filters used in the coil drivers. The resistance of the coil channel is $R \sim 16.5\,\Omega$ and its inductance is $L \sim 214\,\mathrm{mH}$: the L-R circuit results in a pole $R/(2\pi L)$ around $12 - -13\,\mathrm{Hz}$.



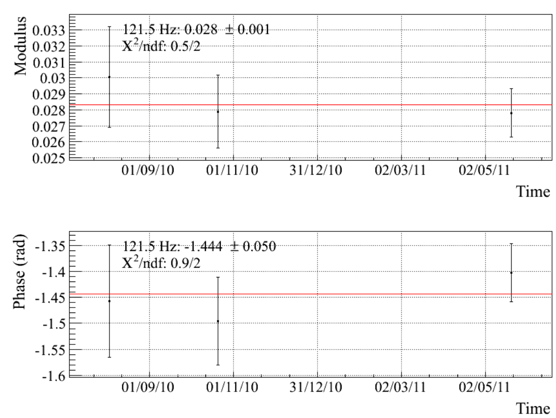
(a) 11.5 Hz



(b) 36.5 Hz

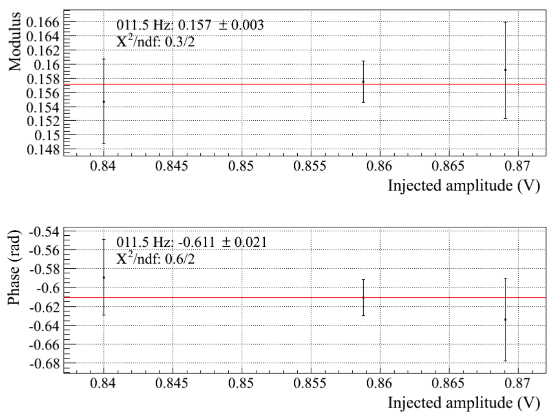


(c) 71.5 Hz

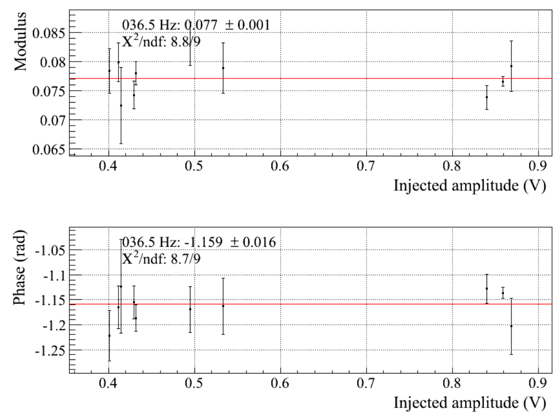


(d) 121.5 Hz

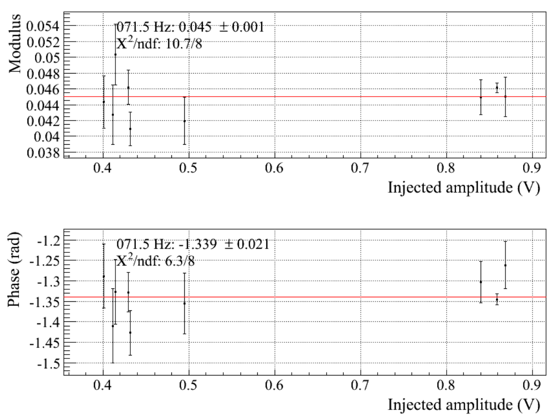
Figure 15: ***Measured WE marionette to mirror actuation (WE, U-D coils, LN1) TF ratio as function of time*** *at four different frequencies. The mirror and marionette actuations have been corrected for their pendulum mechanical models.*



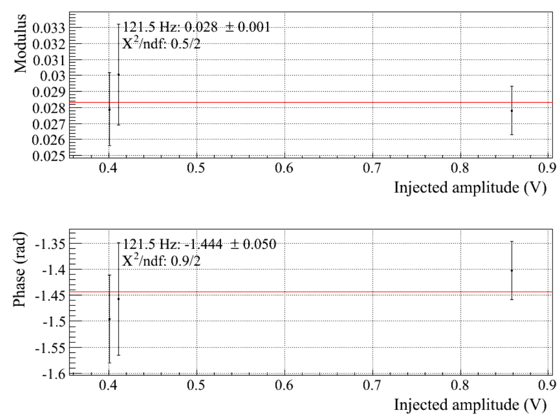
(a) 11.5 Hz



(b) 36.5 Hz

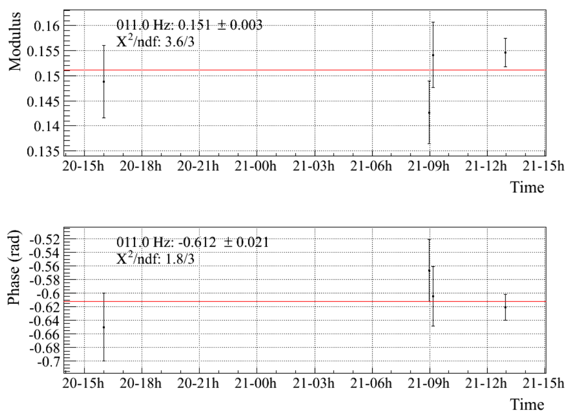


(c) 71.5 Hz

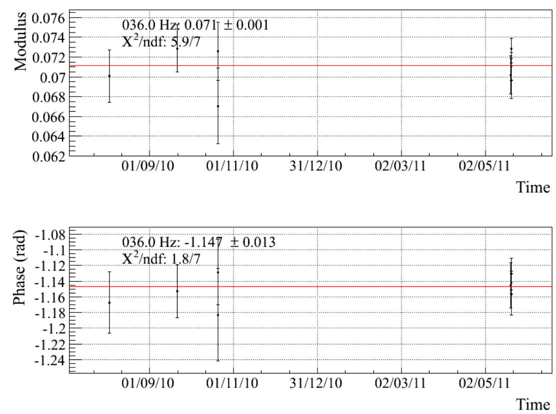


(d) 121.5 Hz

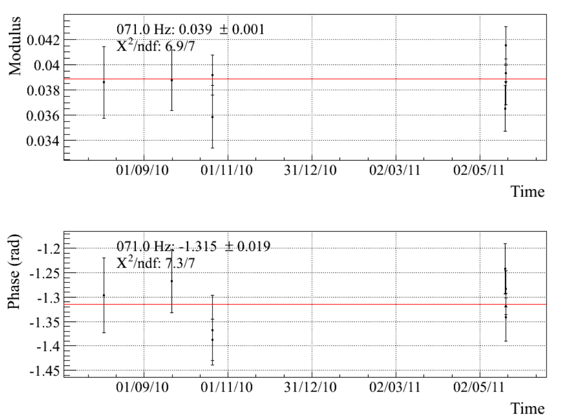
Figure 16: ***Measured WE marionette to mirror actuation (WE, U-D coils, LN1) TF ratio as function of amplitude of injected noise*** *at four different frequencies. The mirror and marionette actuations have been corrected for their pendulum mechanical models.*



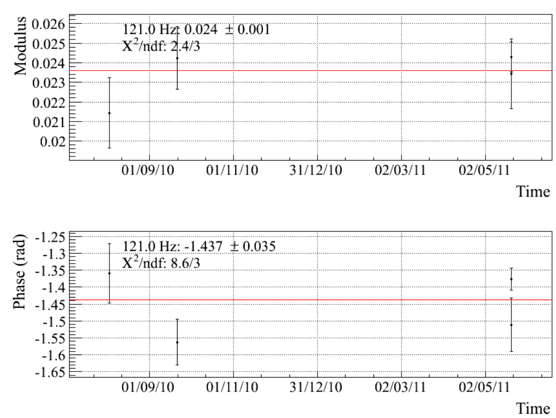
(a) 11.0 Hz



(b) 36.0 Hz



(c) 71.0 Hz



(d) 121.0 Hz

Figure 17: ***Measured NE marionette to mirror actuation (NE, U-D coils, LN1) TF ratio as function of time*** *at four different frequencies. The mirror and marionette actuations have been corrected for their pendulum mechanical models.*

5 Conclusions

A calibration campaign has been done from May 19th to 22nd 2011, before the start of VSR4 (June 3rd 2011). It has been checked that the calibration parameters did not change since VSR3 (July to October 2010). The dark fringe timing and sensing as well as the WE, NE, BS mirrors and the WE, NE marionette actuation response in LN1 mode are thus the same as during VSR3 and given in the note [5].

The PR mirror actuation should not have changed neither since VSR3, but it has not been measured before VSR4.

In case it is decided to switch the end mirror actuation to LN2 mode during the run, the response in LN2 mode of NE and WE mirrors have also been measured. The parametrizations are given in the table 1.

As for the previous runs, a weekly monitoring of the calibration parameters will be done during VSR4.

Online status - The following online processes were already using the sensing and mirror parametrizations from note [5] since a few months:

- the sensitivity and horizon computation,
- the hardware injections (the sign of the injections has been checked on May 31st 2011, see logbook entry 29499),
- the h(t) reconstruction.

Note that the online processes are not ready to deal with the end mirror actuation in LN2 mode.

References

[1] T. Accadia et al. (Virgo collaboration), Class. Quantum Grav. 28 (2011) 025005 *Calibration and sensitivity of the Virgo detector during its second science run* (arXiv:1009.5190).

[2] L. Rolland *Calibration status in September 2009* (2009) VIR-0576A-09.

[3] L. Rolland *VSR2 mirror and marionette actuator calibration* (2010) VIR-0076B-10.

[4] L. Rolland, F. Marion, B. Mours, *Mirror and marionette actuation calibration for VSR1* (2008) VIR-015B-08.

[5] L. Rolland *Virgo calibration during VSR3* (2010) VIR-0610A-10.