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VIRGO Collaboration

VIRGO

MSC Commissioning Progress Report

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1. INTRODUCTION

Last 6 months activities were all focused on two items:

- Actuation noise evaluation and mitigation.
- Control loops implementation on new DSP.

In addition we carried on some standard maintenance activities involving DAC channels and coil drivers. This document is a short report summarizing achieved results.

2. ACTUATION NOISE

A few commissioning shifts were dedicated to the direct measurement of DAC noise contribution to Virgo sensitivity and to eliminate the annoying question of noise up-conversion. Such non linear effect forced us to use a pessimistic value for actuation noise in official noise budget since no direct measurements were available. At the beginning of March 2009 we were able to have such direct measurement with excellent results.

Noise of DAC channels driving Marionettes on long arms was indicated to be one of the highest noise sources in Virgo Noise Budget. DAC outputs are lowpass filtered in order to reduce by a factor 10 the noise contribution above 10 Hz. The filter is implemented using a capacitor that can be easily excluded using a switch. In standard operation filter is on. When lowpass filter is excluded (and also its highpass digital counterpart implemented in DSP), DAC noise contribution is increased by a factor 10.

Removing lowpass filters from marionette actuators on long arms we can see the effect of DAC noise on Virgo sensitivity (Figure 1, data taken on March 3rd 2009). Below 40 Hz sensitivity is affected by DAC noise and at 10 Hz sensitivity grows from about 2e-20 up to 5e-20 1/rtHz. From this plot we can compute DAC noise levels assuming the following values for transfer function between DAC output and mirror displacement: DC Displacement: 3.4 um/V (using both horizontal coils, each coil contributes with one half of this value). First Marionette Resonance: 450 mHz Second Marionette Resonance: 980 mHz

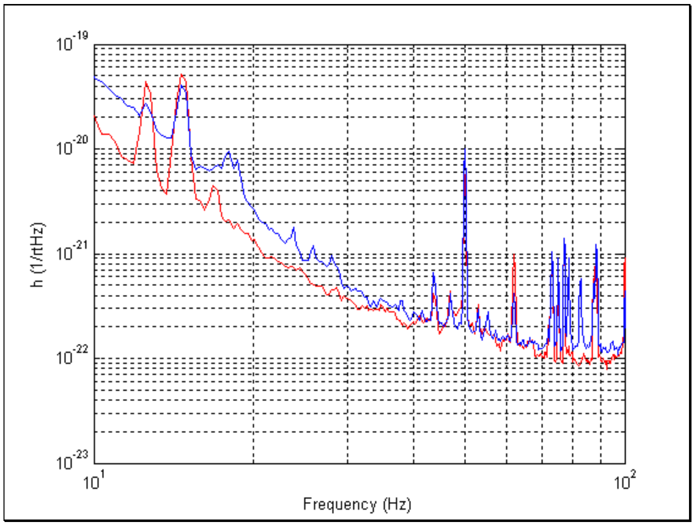

Figure 1 Virgo Sensitivity with (red) and without (blue) shaping filters

2.1 *Dithering*

Once measured the DAC noise using Virgo interferometer, we decided to test dithering technique. For such purpose we switch back on the shaping filters at WE in order to put in evidence the only NE contribution. As dithering signal we used a 5 mV peak sine wave at 353 Hz (a calibration line already available at mirror level) and the effect is shown in the following picture. The left picture is the dark fringe signal while the right plot shows the spectrum of the signal driving the two DACs channels.

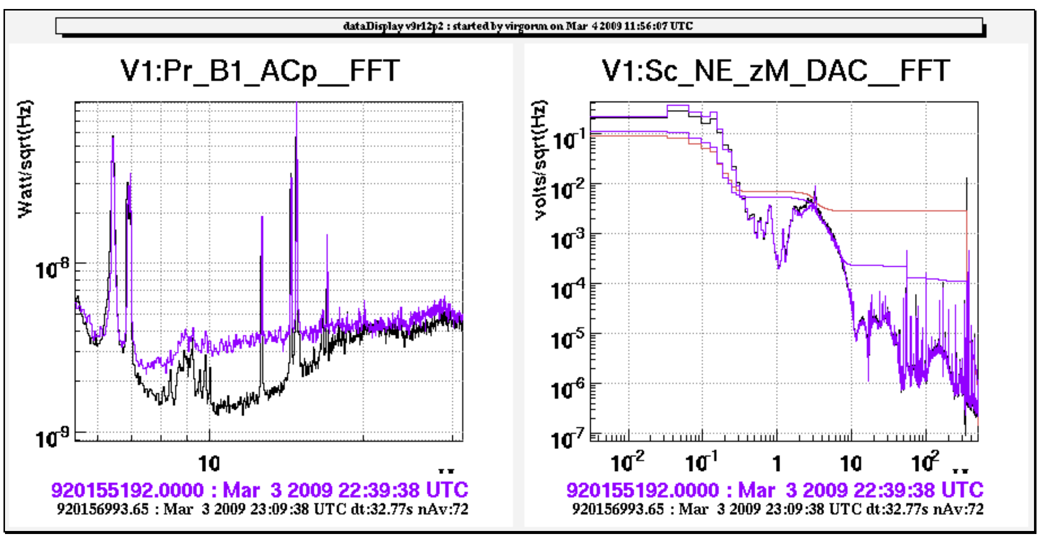

Figure 2 Dithering effect on Virgo dark fringe and DAC signal spectrum

The dithering signal removes the DAC up-conversion effect with results compatible with what obtained last year in laboratory tests where we measured a reduction factor equal to 4 at 10 Hz. In this case reduction is only something more than a factor two but we are clearly limited by a different noise source (slopes of two curves are different).

We can also notice in next picture that the difference between signal spectra at WE, shaping filters and no dithering, and at NE, no shaping filters and dithering.

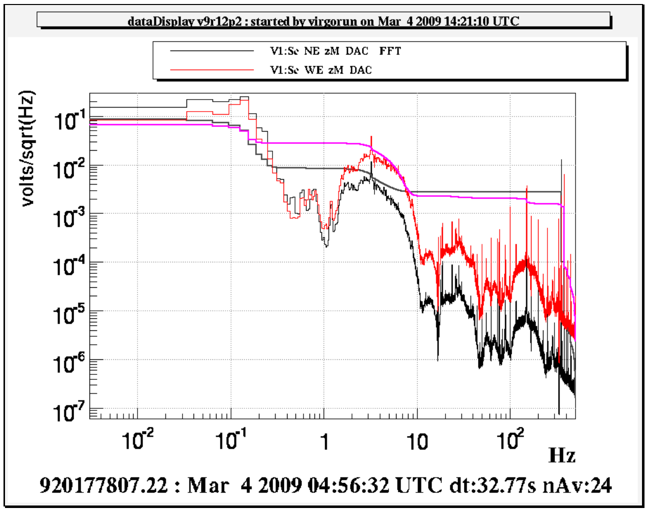

Figure 3 Comparison between DAC signal at WE (shaping filter on, dithering off, red line) and at NE (shaping filter off, dithering on, black line). Both rms values are below 100 mV.

The two spectra have similar rms values at frequencies larger than 10 Hz. The small difference pushes towards the conclusion that there is no need of adding any dithering signal since, thanks to shaping filters, higher frequency components are already available in the DAC signal.

The DAC noise model determined in laboratory last year can be now updated keeping into account measurement done with Virgo interferometer.

Without signal

$$\tilde{n}_0 \cong \frac{1200}{\sqrt{f}} + 350 \quad \frac{nV}{\sqrt{Hz}}$$

With low-pass signal and dithering

$$\tilde{n}_D \cong \frac{2500}{\sqrt{f}} + 350 \quad \frac{nV}{\sqrt{Hz}}$$

2.2 *Effect on Virgo Sensitivity*

Once determined a more accurate model we can update noise budget for what concerns suspension actuators.

All long arms marionette actuators are equipped with shaping filters having as transfer function:

$H_{SMar}(s) = \dfrac{s/\omega_z + 1}{s/\omega_p + 1}$, with pole at about 0.9 Hz and zero at about 9 Hz.

Marionette transfer function (displacement along beam direction in respect with applied force) can be simplified taking into account only the two main modes ad 450 and 980 mHz. The DC gain is assumed to be

$g_{Mar} = 1.7 \cdot 10^{-6} \quad m/V$ (1 coil: applying 1 V at both coil drivers, mirror displacement is 3.4 um)

If z correction forces are applied only at end suspensions, input suspensions marionette coils are driven by a very small signal not producing any up conversion. The power spectrum density (m^2/Hz) of displacements is:

$$\tilde{X}_{NE}(f) = \tilde{X}_{WE}(f) = 2 \cdot g_{Mar}^2 |H_{SMaer}(f)|^2 |H_M(f)|^2 N_D(f)$$

$$\tilde{X}_{NI}(f) = \tilde{X}_{WI}(f) = 2 \cdot g_{Mar}^2 |H_{SMaer}(f)|^2 |H_M(f)|^2 N_0(f)$$

Total noise due to arms marionette actuators is the sum of the 4 components

$$\tilde{X}_{ArmsMar}(f) = 4 \cdot g_{Mar}^2 |H_{SMaer}(f)|^2 |H_M(f)|^2 N_0(f) + 4 \cdot g_{Mar}^2 |H_{SMaer}(f)|^2 |H_M(f)|^2 N_D(f) =$$
$$= 4 \cdot g_{Mar}^2 |H_{SMaer}(f)|^2 |H_M(f)|^2 \cdot [N_0(f) + N_D(f)]$$

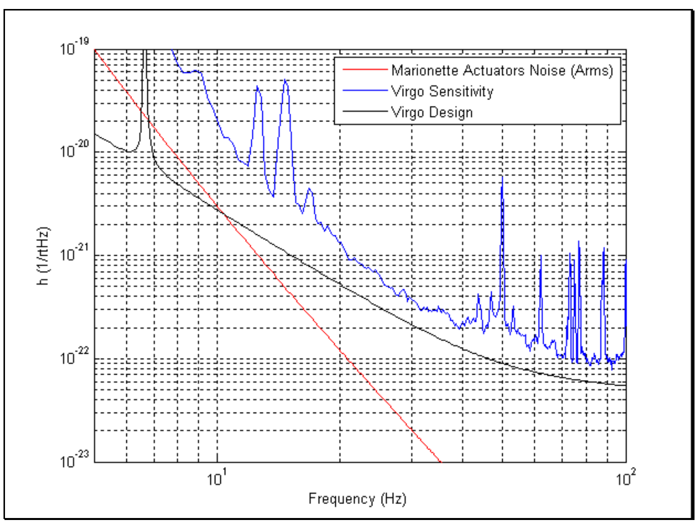

Figure 4 Noise Budget: Arms Marionette Actuators (March 3rd data)

Actuation noise on Marionette is within Virgo specs above 10 Hz. Keeping into account that at present we use only a small fraction of available dynamical range (see rms plot in Figure 3), this configuration shall allow meeting also Virgo+ and Adv Virgo specs (with about 90% duty cycle).

Different is the case for reference mass actuators. Input suspensions are equipped with a very large series resistor (6 kOhm) and therefore their noise is negligible compared with terminal towers.

At terminal towers we have a second order shaping filters (2 poles at 0.9 Hz and two zeros at 9 Hz). Mechanical transfer function is the one of a simple pendulum with 600 mHz resonant frequency. DC gain is assumed to be $g_{mir} = 5.5 \cdot 10^{-6} \quad m/A$ (1 coil: applying 1 A in 2 coils mirror displacement is 11 um)

Output voltage is divided by a series resistor whose value is a function of low noise mode:

Rs = {300,1200,2400,4800} (excluding cable+coil+protection = 20 Ohm)

Reference mass is equipped with 4 coils but only two are currently used ('Up' and 'Down')

$$\tilde{X}_{NE}(f) = \tilde{X}_{WE}(f) = 2 \cdot g_{mir}^2 / R_S^2 \cdot |H_{Smir}(f)|^2 |H_{Mmir}(f)|^2 \tilde{N}_D(f) + 2 \cdot g_{mir}^2 / R_S^2 \cdot |H_{Smir}(f)|^2 |H_{Mmir}(f)|^2 \tilde{N}_0(f) =$$
$$= 2 \cdot g_{mir}^2 / R_S^2 \cdot |H_{Smir}(f)|^2 |H_{Mmir}(f)|^2 \cdot [\tilde{N}_0(f) + \tilde{N}_D(f)]$$

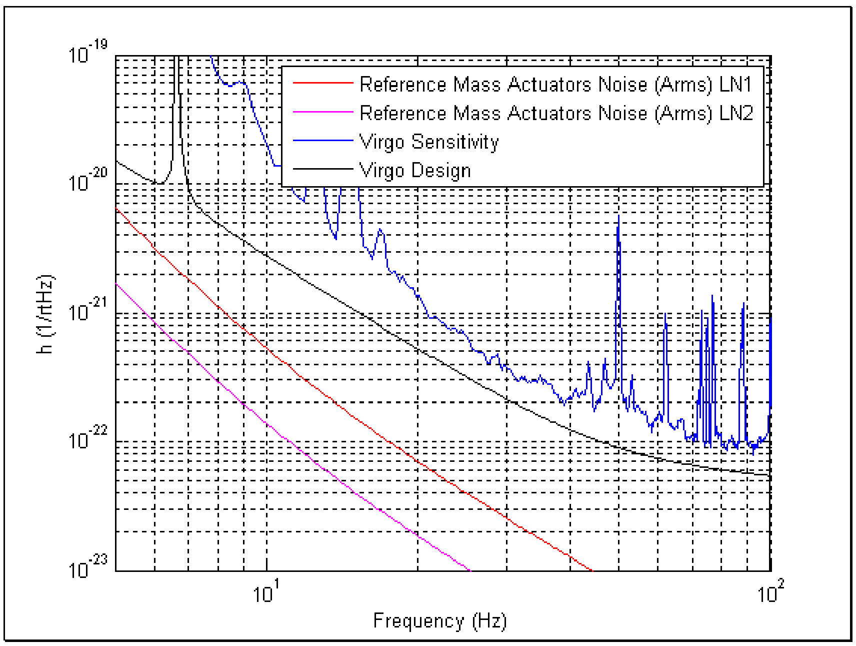

Figure 5 Arms Reference Mass Actuators (LN1 and LN2) March 3rd Data.

2.3 *Actuation Noise Conclusions*

- A direct measurement of DAC noise contribution to actuation noise ware taken.
- Up conversion (NL noise) is about 8 uV/sqrt(f) and not 12 uV/sqRT(f) as supposed
- Dithering reduces this noise down to 2.5 uV/sqrt(f).
- zCorr spectrum already contains 'dithering' lines but since we can add an high frequency line without any cost we will add such lines. Moreover, where low frequency part of zCorr is applied on marionette (long arms suspensions), up conversion should be negligible even without any dithering.
- Virgo specs fully met with today configuration.

2.4 *Summary of Hardware Configuration Changes*

- New coil drivers were installed at Beam Splitter suspension. Coil driver was set with exactly the same resistor value as the one installed at terminal suspensions. The change did not produce appreciable result (up to now).
- Shaping filters were added ad signal recycling mirror (also in this case we had no appreciable results)
- General maintenance. Several DAC channels were replaced due to excess noise, excess offset voltage or missing codes.

3. NEW DSP

New DSPs are ready to be installed. Impact on Virgo electronics and software is minimal since replacement of a total of 12 boards, if replacing only at long suspensions, doesn't require any additional change in any other piece of hardware and software.

3.1 *Hardware*

The new multi DSP board developed last year to replace obsolete DSPs used for suspension control were made available (30 boards). Hardware and firmware tests successfully completed.

3.2 *Software*

Porting of DSP compiler to the new platform was completed as well and several tests were carried out using North Input and West Input suspension. Result is more than excellent since we are able to use the code developed for old DSP without changing a single line of code and therefore with null impact on users. All control loops and interfaces towards other Virgo subsystems were successfully tested. New DSPs offer a much lager computation power and communication bandwidth allowing implementation of more performing controller.

3.3 *DSP Conclusion*

In spite of such excellent results, Detector Coordinator P. Rapagnani and Commissioning Coordinator E. Calloni, decided not to replace old DSP. Even if I fully agree with the fact that old DSP allow Virgo operation, I repeat once again that not replacing DSP constitute an obstacle to further development of the Suspension Control. Moreover, starting science run with boards that are now 10-12 years old constitutes a major risk.

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