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Mirror actuation configuration during VSR1

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Contents

1 Introduction

The control of the Virgo mirror position is based on electro-magnetic actuators: coils induce a magnetic field that act on the magnets glued on the mirrors in order to control their angular and longitudinal movements.

Only the mirror longitudinal motion is used in the calibration and h-reconstruction processes. Only the actuators used for the longitudinal control are described in this note. The input of the actuation is the control signal Sc_ ∗ _zCorr, in V ; the output is the force acting on the mirror.

The configurations of the mirror actuation used during VSR1 are described in this note.

2 The mirror longitudinal control channels

The mirrors can be longitudinally controlled through different magnets and associated coil actuation. During VSR1, the NE and WE mirrors were controlled using two channels: the up (CoilU) and down (CoilD) coils. The BS mirror was controlled using four channels: the up-left (CoilUL), up-right (CoilUR), down-right (CoilDR) and down-left (CoilDL) coils. The PR mirror was controlled using the up and down channels [1].

The input mirrors, NI and WI, were not longitudinally controlled during VSR1 [2]. However, signal injections were done on the NI mirror in order to check the h-reconstruction and to perform hardware injections. The input mirror injections were done through two channels, CoilU and CoilD.

3 General actuation processing

To control the mirror position in z, the coil drivers are converting a digital control signal (in V) into an analog current (in A), as described in the figure 1. It can be separated into three distinct parts: the digital computing in the DSP, the DAC+analog coil driver, and the coil current sensing part. The details of the electronics differ from a channel to another.

The suspensions can be set into two modes (except PR):

- the high-power mode (HP) is used to acquire the lock of the ITF.
- the low-noise mode (LN) is used to control the locked ITF. The noise reduction has a counterpart: the input signal dynamic is reduced compared to the HP mode.

[1] The angular motion of the mirrors was controlled through the marionettes. The marionnettes were also used to control the longitudinal motion of the NE and WE mirrors below a few tenth of Hz. At the beginning of the run (up to June 6th 2007, logbook entry 16978), the NI and WI marionnettes were also used for the longitudinal control.

[2] except at low frequency, through the marionettes, before June 6th 2007.

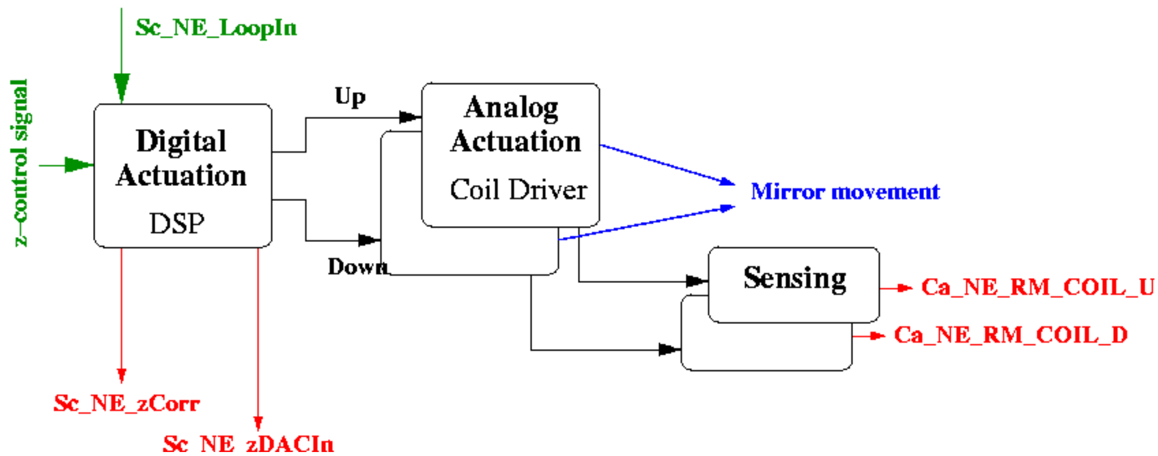

Figure 1: ***Mirror actuation principle.***

The gains and filters in both HP and LN channels are set such that the transfer functions of the actuation in HP and LN mode are the same. In practice, 10% difference have been measured [4].

A brief summary of every parts are given in this section.

3.1 Digital part: the DSP

The two digital input signals (in V) of the mirror longitudinal actuation are the calibration signal *LoopIn*[3] and the signal from the longitudinal control loop. Both are digitally summed into a DSP, creating the signal *zCorr*[4] (at 10 kHz, in V). *zCorr* then goes through gains and digital emphasis filters [5] in the DSP, accordingly to the mode of the suspension. The signal is then written into a DAC at 10 kHz.

The output signal of the DSP through the HP channel is monitored as *zDACIn*[6] (in V). It is used to check the signal sent to the DAC in HP mode [7]. No monitoring is done on the LN channel DSP output.

[3] The complete names of such channels are *Sc_NE_LoopIn* for the NE tower for example.
[4] The complete names of such channels are *Sc_NE_zCorr* for the NE tower for example.
[5] The emphasis/de-emphasis filters set before/after the DAC are used to reduce the DAC noise at high frequency. During VSR1, the emphasis filters were composed of a simple zero and a simple pole.
[6] The complete names of such channels are *Sc_NE_zDACIn* for the NE tower for example.
[7] *zDACIn* is computed and monitored whatever the mode of the suspension is. But it is sent to the DAC only in HP mode.

3.2 DAC and analogic coil driver

The DAC dynamic is ±10V. The DAC output voltage goes through analog de-emphasis filters and is converted into current flowing into the coil. The conversion is made through the impedance of the coil and serie resistors or through a trans-conductance amplifier.

The current is converted by the coil+magnet pairs into an electromagnetic force acting on the mirror magnets to move the mirror along the longitudinal z direction.

A coil impedance has been measured in [2]: its intrinsic inductance and resistance are $L_C = 3.386 \pm 0.007\,\mathrm{mH}$ and $R_C = 5.97 \pm 0.07\,\Omega$. The dispersion of both parameters in the different coils are of the order of 5% [3].

Two serie resistors are used in both HP and LN channels: $R_p \sim 39\,\Omega$ (protection resistor to limit the current in the coil, added in January 2007) and $R_m \sim 1\,\Omega$. The additionnal serie resistor R_s used in LN mode is of a few kΩ.

3.3 Coil current sensing channel

The current flowing in the coil is measured as the voltage at the pin of a read-out resistor. The signal then goes through shaping filter and a gain of 2, and is sent to an ADC. The digital output voltage is stored in the data as RM_CoilU[8].

The pole and zero of the shaping filters have not be measured precisely for every channels. Their nominal values are 3 Hz and 97 Hz.

4 Actuation of the NE, WE and BS mirrors

Details about the actuation of the BS and end mirrors are given in this section. A synoptic of the actuation chain is given in the figure 4. The values of the relevant gains, poles and zeros are given in the tables 1 and 2.

The BS and end mirror channels have two DACs, one for each suspension mode (HP and LN). It permits a smooth transition from a mode to another.

4.1 HP mode

In the DSP, $zCorr$ is directly sent to DAC ($G_{DSP}^{HP} = 1$).

In the coil driver, the DAC output voltage is converted into current through a trans-conductance amplifier with a gain of $G_{CD}^{HP} = 0.1947\,\mathrm{A/V}$. The transfer function of the amplifier has a cut-off at a few kHz. The trans-conductance amplifier is supplied with a ±24 V with a linear range around ±20 V.

[8] The complete names of such channels are $Ca\_NE\_RM\_CoilU$ and $Ca\_NE\_RM\_CoilD$ for the NE tower for example. It is also measured another way as $Sc\_NE\_RM\_CoilU$ and $Sc\_NE\_RM\_CoilD$.

The current is monitored at the pins of a resistor with value of $R_m \sim 1\,\Omega$. It is then digitized through an ADC and stored in the data. Since there is a gain 10 in the monitoring channel, the total gain of the monitoring channel is $G_S^{HP} \sim 10\,\mathrm{V/A}$.

Dynamic - In HP mode, the dynamic is limited by the trans-conductance amplifier.

The maximum voltage that can be delivered at the amplifier output is 20 V (in the linear range). The impedance at its output, from the coil and serie resistors in HP mode, is $(R_p + R_c + R_m) \sim 50\,\Omega$. The maximum current flowing in the coil is thus 0.4 A. The amplifier conversion factor being $G_{CD}^{HP} = 0.1947\,\mathrm{A/V}$, the maximum voltage that can be sent to the amplifier is 2 V.

In HP mode, the dynamic of the $zCorr$ signal is thus $\pm 2\,\mathrm{V}$, and the dynamic of the current if $\pm 0.4\,\mathrm{A}$.

In fact, the coil and serie resistors behave like a simple zero: $R_{tot}(1 + \mathrm{j}\frac{f}{f_0})$ with $R_{tot} = R_p + R_c + R_m \sim 50\,\Omega$ and $f_0 = R_{tot}/(2\pi L_c) \sim 2.5\,\mathrm{kHz}$. The dynamic is thus reduced at high frequency, when the coil impedance cannot be neglected.

4.2 LN mode

In the DSP, a gain G_{DSP}^{LN} and digital emphasis filters (simple pole and zero) are applied to the $zCorr$ signal before it is sent to the DAC.

In the coil driver, the DAC output voltage V_{DAC} goes through gains and de-emphasis filters and is converted into current through serie resistors. Neglecting the filters, the gain of the coil driver in LN mode is:

$$G_{CD}^{LN} = (0.1947 \times 10) \times \frac{1}{R_s + R_p + R_c + R_m}\ \mathrm{A/V}$$

Two resistors with a total resistance R_s of a few kΩ are added compared to the HP channel. For the end mirrors, with $R_s = 6\,\mathrm{k}\Omega$, the gain of the coil driver is thus

$$\left(G_{CD}^{LN}\right)_{NE,WE} \sim 0.323 \times 10^{-3}\ \mathrm{A/V}$$

The current is monitored at the pins of one of the additionnal resistor $R_s/2$. It then goes through the same shaping filter, gain 2 and ADC than in HP mode. The total gain of the monitoring channel is $G_S^{LN} \sim 2 \times R_s/2\,\mathrm{V/A}$.

For the NE and WE mirror actuation, only one emphasis/de-emphasis filter (3-28 Hz) was used up to July 11th 2007. A second one (15-80 Hz) has been added at this time.

For the BS mirror actuation, two emphasis/de-emphasis filters were used from the beginning of VSR1 (from May 10th 2007).

The gains and emphasis filters set in the DSP are set in order to compensate the additionnal de-emphasis filters and resistors in the coil driver in LN mode. Concerning the gain:

$$G_{DSP}^{HP} \times G_{CD}^{HP} \sim G_{DSP}^{LN} \times G_{CD}^{LN}$$

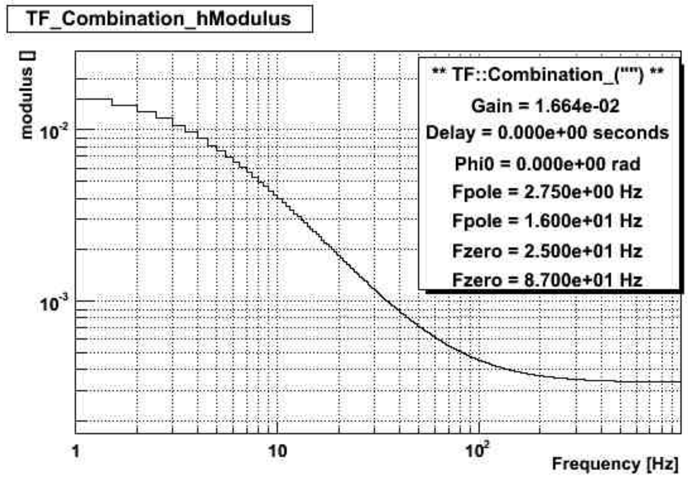

Figure 2: ***Maximum amplitude (in V) of a single line injected on*** *zCorr to the end mirrors in LN mode, with two emphasis/de-emphasis filters (after July 11th, 2007).*

Dynamic - In LN mode, the dynamic is limited by the DAC, with range ± 10 V. The output signal of the DSP have thus to be lower than 10 V. Since there are filters in the DSP, the dynamic of *zCorr* for line injection depends on the frequency. The maximum amplitude of a single injected line on *zCorr* as function of frequency is given in the figure 2.

The maximum current flowing in the coil is the current induced by a 10 V DAC output in the serie resistor (the impedance of the coil can be neglected since the pole is of the order of 300 kHz). Since there are de-emphasis filters in the coil driver, the dynamic depends on frequency.

Before July 11th, 2007, only one emphasis/de-emphasis filter was used. The dynamic was thus larger.

5 Actuation of the NI and WI mirrors

A synoptic of the actution chain of the input mirrors is given in the figure 5. The values of the relevant gains, poles and zeros are given in the tables 1 and 2.

Since most of the details are similar to the end mirror actuation, only the differences are given here.

The input mirror channels have a single DAC used for both the LN and HP mode. The transition from a mode to another is not smooth.

There is not trans-conductance amplifier. The DAC voltage output is converted into the current in the coil through the serie resistors in both HP and LN modes.

5.1 HP mode

In HP mode, the *zCorr* signal is filtered through two emphasis filters in the DSP while only one de-emphasis filter is used in the coil driver. The gain in the DSP is set to take into account the serie resistors R_p and R_c.

5.2 LN mode

In LN mode, the two de-emphasis filters used in the coil drivers are compensated in the DSP. Additionnal serie resistors $R_s = 6\,\text{k}\Omega$ are added. The gain in the DSP is modified accordingly.

5.3 Dynamic

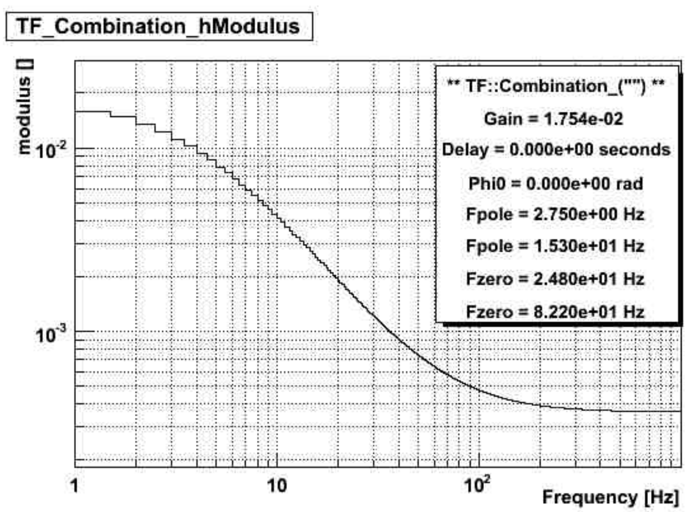

Figure 3: ***Maximum amplitude (in V) of a single line injected on*** *zCorr to the input mirrors in LN mode, with two emphasis/de-emphasis filters (after July 11th, 2007).*

The dynamic is limited by the DAC ±10 V range. Since the two emphasis filters are used both in LN and HP modes, the dynamics differ by an overall gain only. The figure 3 gives the *zCorr* dynamic for single line injections in LN mode. In HP mode, the dynamic is increased by a factor $G_{DSP}^{LN}/G_{DSP}^{HP} \sim 120$.

5.4 Notes

For the input mirrors, the emphasis filters are not compensated channel by channel: an average pole and zero are used for the NI and WI channels respectively.

Before July 11th, 2007, only one emphasis/de-emphasis filter (3-28 Hz) was used, both in HP and LN modes. The filter added on July 11th (15-80 Hz) in the LN channel of the coil driver was compensated in the DSP in LN mode, but also set in HP mode.

6 Actuation of the PR mirror

The PR mirror actuation has only one channel that corresponds to the HP channels of the BS and end mirrors. As their is a gain 10 in the DSP, the maximum *zCorr* value is 1 V.

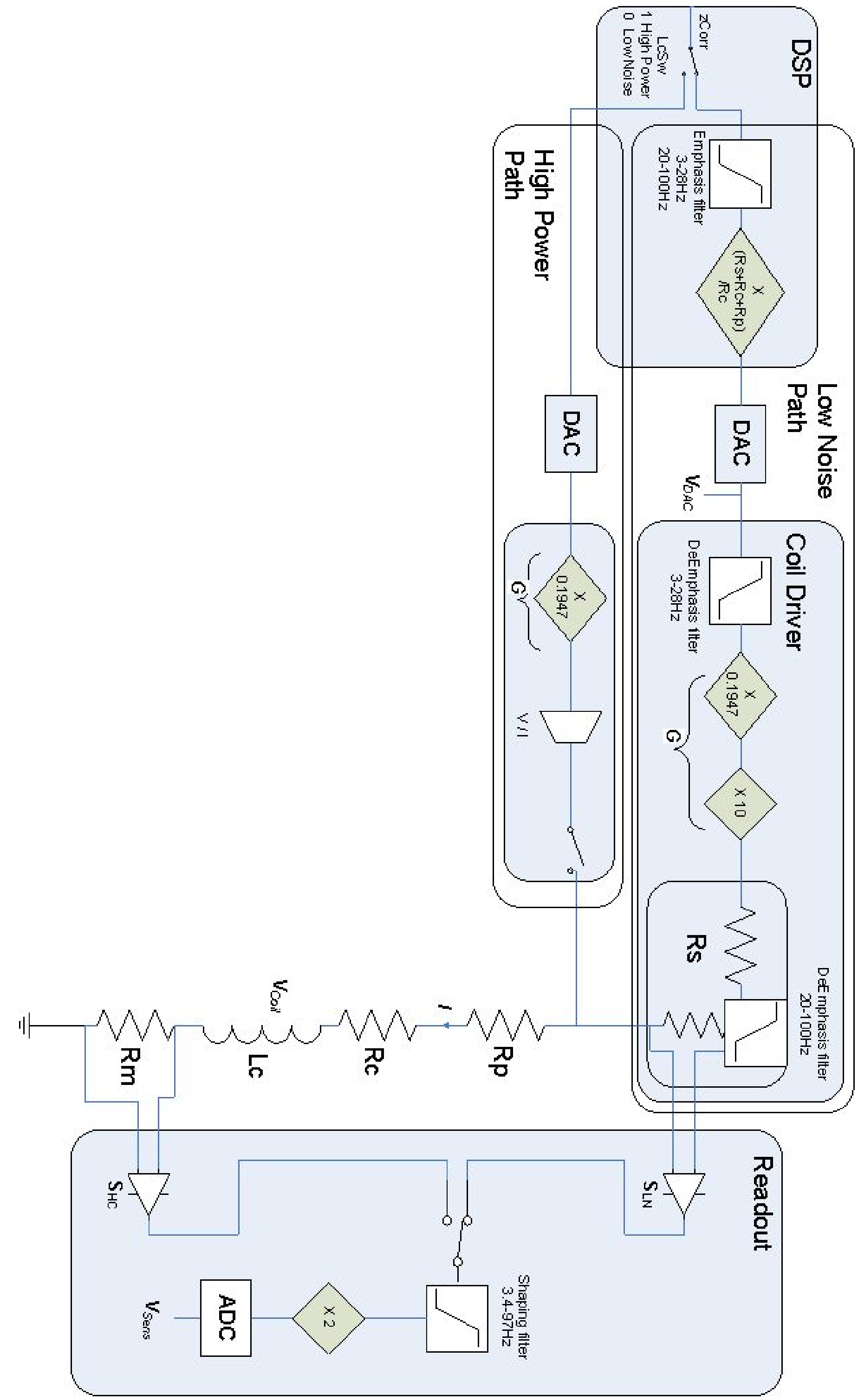

Figure 4: ***Synoptic of the NE, WE and BS coil drivers.***

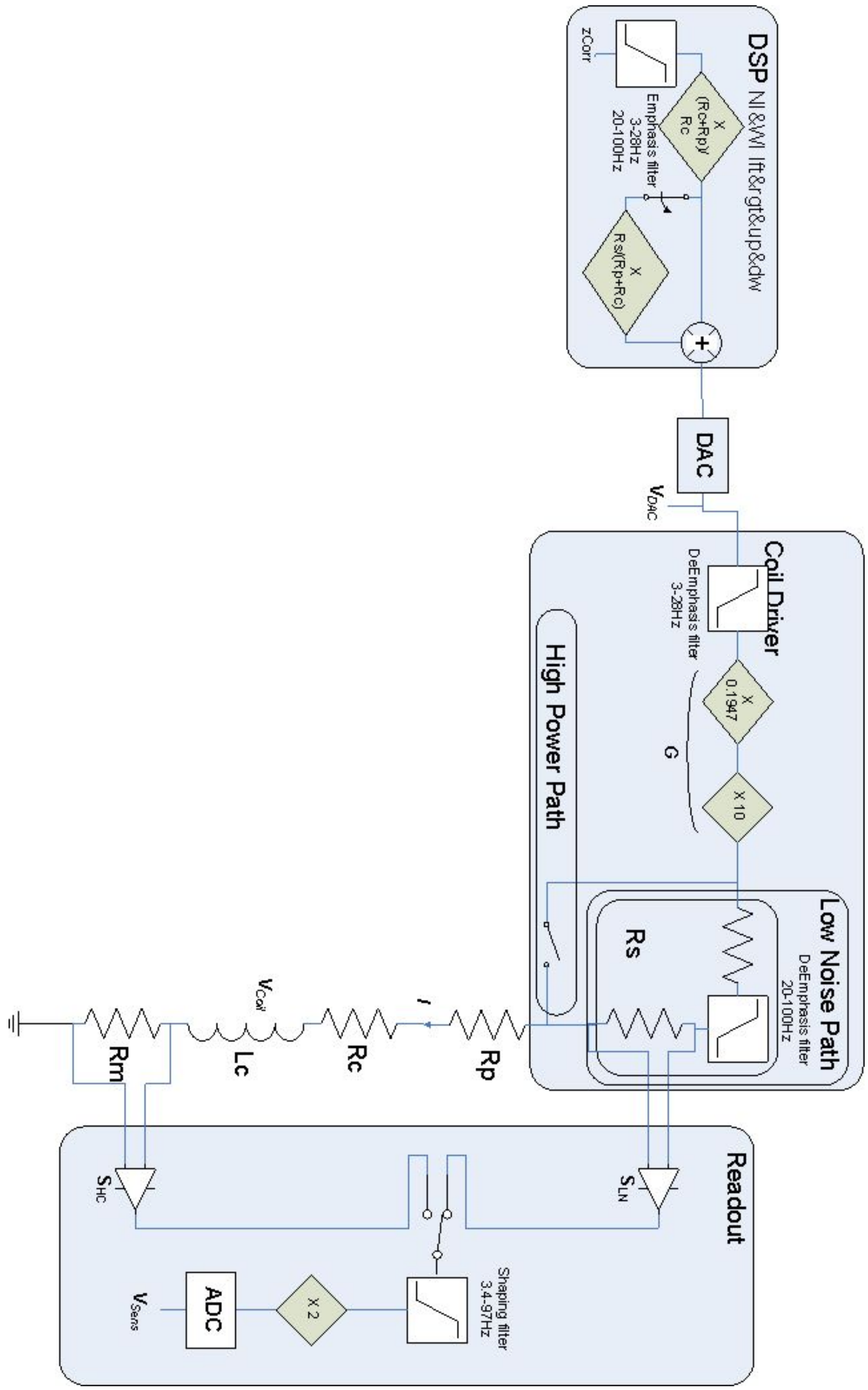

Figure 5: ***Synoptic of the NI and WI coil drivers.***

	Digital actuation			Analog actuation			Sensing		
	emphasis zero (Hz)	emphasis pole (Hz)	G_{DSP}^{HP} (V/V)	de-emphasis pole (Hz)	de-emphasis zero (Hz)	G_{CD}^{HP} (A/V)	G_S^{HP} (V/A)	shaping zero(Hz)	shaping pole (Hz)
NE-up	-	-	1	-	-	0.1947	10	3.4	97
NE-down	-	-	1	-	-	0.1947	10	3.4	97
WE-up	-	-	1	-	-	0.1947	10	3.4	97
WE-down	-	-	1	-	-	0.1947	10	3.4	97
NI-up	2.75, 15.3	24.8, 82.2	4.7	2.75	24.8	0.039	10	3.4	97
NI-down	2.75, 15.3	24.8, 82.2	4.7	3 *	28 *	0.039	10	3.4	97
WI-up	2.76, 16.6	25.0, 89.1	4.7	2.75	24.9	0.039	10	3.4	97
WI-down	2.76, 16.6	25.0, 89.1	4.7	2.78	25.3	0.039	10	3.4	97
BS-UL	-	-	0.5	-	-	0.1947	10	3.4	97
BS-UR	-	-	0.5	-	-	0.1947	10	3.4	97
BS-DL	-	-	0.5	-	-	0.1947	10	3.4	97
BS-DR	-	-	0.5	-	-	0.1947	10	3.4	97
PR-up	-	-	10	-	-	0.1947 ?	10 ?	3.4?	97?
PR-down	-	-	10	-	-	0.1947 ?	10 ?	3.4?	97?

Table 1: ***Parameters of the actuation channels of the different mirrors in HP mode.*** *Before July 11th 2007, only one emphasis filter was used in the DSP (3-28 Hz).*

	Digital actuation			Analog actuation			Sensing		
	emphasis		G_{DSP}^{LN}	de-emphasis		G_{CD}^{LN}	G_S^{LN}	shaping	
	zero (Hz)	pole (Hz)	(V/V)	pole (Hz)	zero (Hz)	(A/V)	(V/A)	zero(Hz)	pole (Hz)
NE-up	2.76, 15.8	25.0, 82.6	601	2.76, 15.8	25.0, 82.6	0.323×10^{-3}	6 000	3.4	97
NE-down	2.71, 17.7	24.5, 87.3	601	2.71, 17.7	24.5, 87.3	0.323×10^{-3}	6 000	3.4	97
WE-up	3.27, 14.5	29.7, 81.5	601	3.27, 14.5	29.7, 81.5	0.323×10^{-3}	6 000	3.4	97
WE-down	3.07, 16.4	27.8, 84.6	601	3.07, 16.4	27.8, 84.6	0.323×10^{-3}	6 000	3.4	97
NI-up	2.75, 15.3	24.8, 82.2	570	2.75, 15.5	24.8, 82.0	0.323×10^{-3}	6 000	3.4	97
NI-down	2.75, 15.3	24.8, 82.2	570	3 *, 15.2	28 *, 82.4	0.323×10^{-3}	6 000	3.4	97
WI-up	2.76, 16.6	25.0, 89.1	570	2.75, 16.3	24.9, 89.0	0.323×10^{-3}	6 000	3.4	97
WI-down	2.76, 16.6	25.0, 89.1	570	2.78, 17.0	25.3, 89.2	0.323×10^{-3}	6 000	3.4	97
BS-UL	2.71, -17.20	24.8, -109.1	51	2.71, -17.20	24.8, -109.1	1.926×10^{-3}	1 000	3.4	97
BS-UR	2.80, -16.16	25.5, -103.6	51	2.80, -16.16	25.5, -103.6	1.926×10^{-3}	1 000	3.4	97
BS-DL	2.78, -15.72	25.3, -100.9	51	2.78, -15.72	25.3, -100.9	1.926×10^{-3}	1 000	3.4	97
BS-DR	3.03, -15.85	27.5, -101.3	51	3.03, -15.85	27.5, -101.3	1.926×10^{-3}	1 000	3.4	97

Table 2: ***Parameters of the actuation channels of the different mirrors in LN mode.*** *Before July 11th 2007, only one emphasis/de-emphasis filter (3-28 Hz) was used in the end and input mirror actuation channels. The second one (15-80 Hz) was added on July 11th. The * indicate a nominal value which has not been precisely measured.*

References

[1] A. Gennai, VIRGO note (2004) VIR-SPE-PIS-4900-121

[2] P. Puppo, P. Rapagnani, VIRGO note (2005) VIR-NOT-ROM-1390-311

[3] P. Puppo, private discussion, 2007

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