Vertical control : Suspension ModeCleaner

LUCIA TROZZO

Vertical Control

This control is implemented in the region of the low frequencies, where the 'background signal' is considerable.

This control is useful to stabilize the altitude of the suspended obejcts, as the mirrors.

In particular this analysis is restricted in the range of [0.100, 10] Hz.

Abstract

- Measurement of the vertical transfer function of suspensions:

  Input Actuators

  Output Sensors (Lvdt,Acc)

  Input seismic excitation

  Output Sensors (Lvdt,Acc)

- Setup of the virtual sensor and strategy implementation HP/LP
- Comparing between different strategy HP/LP
- Controller optimization
- Performance Analisys
- OCTOPUS DATA.

Measurement of the vertical transfer function of suspensions (TF)

This measurement is useful to caracterize the response of the system to vertical excitation.

1) **Input** Actuators **Output** Sensors (Lvdt,Acc)

In this way we have the measurement of TF that characterizes the plant process (M).

2) **Input** seismic excitation **Output** Sensors (Lvdt,Acc)

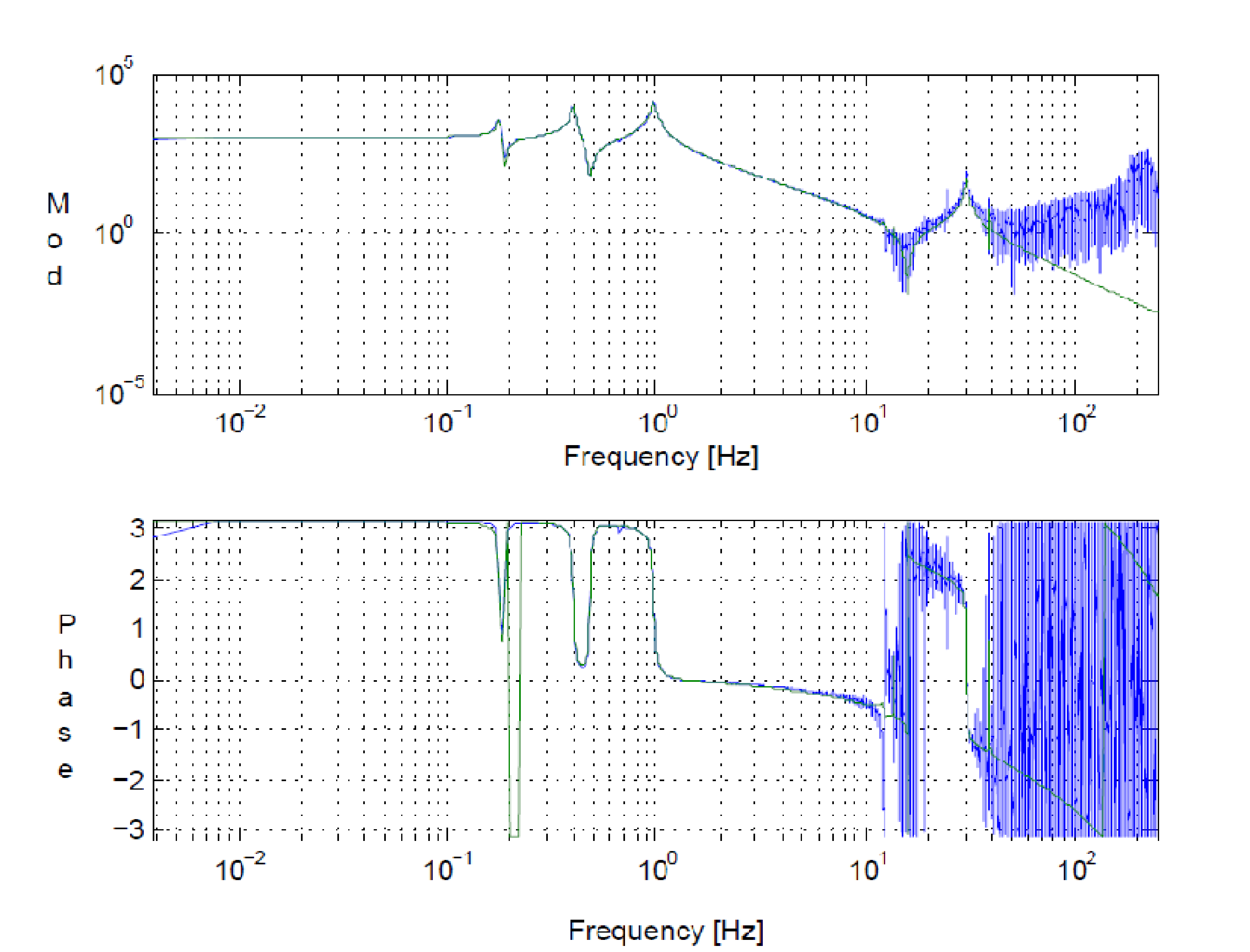
These measurements, in order to project the seismic excitation on the sensors (Lvdt,Acc) of the suspensions, can be used as filters.

In this way, we can have a responce of the suspension to seismic excitation .

This procedure is useful because we can have a 'indirect measurement' of the signal open loop also when the control loop is closed in closed loop condition.

In this way we obtein the signal open loop (SOL) starting from the seismic excitation.

In particular, these TFs are mesaured by the sensors of F0 of the tower Mode Cleaner (MC).



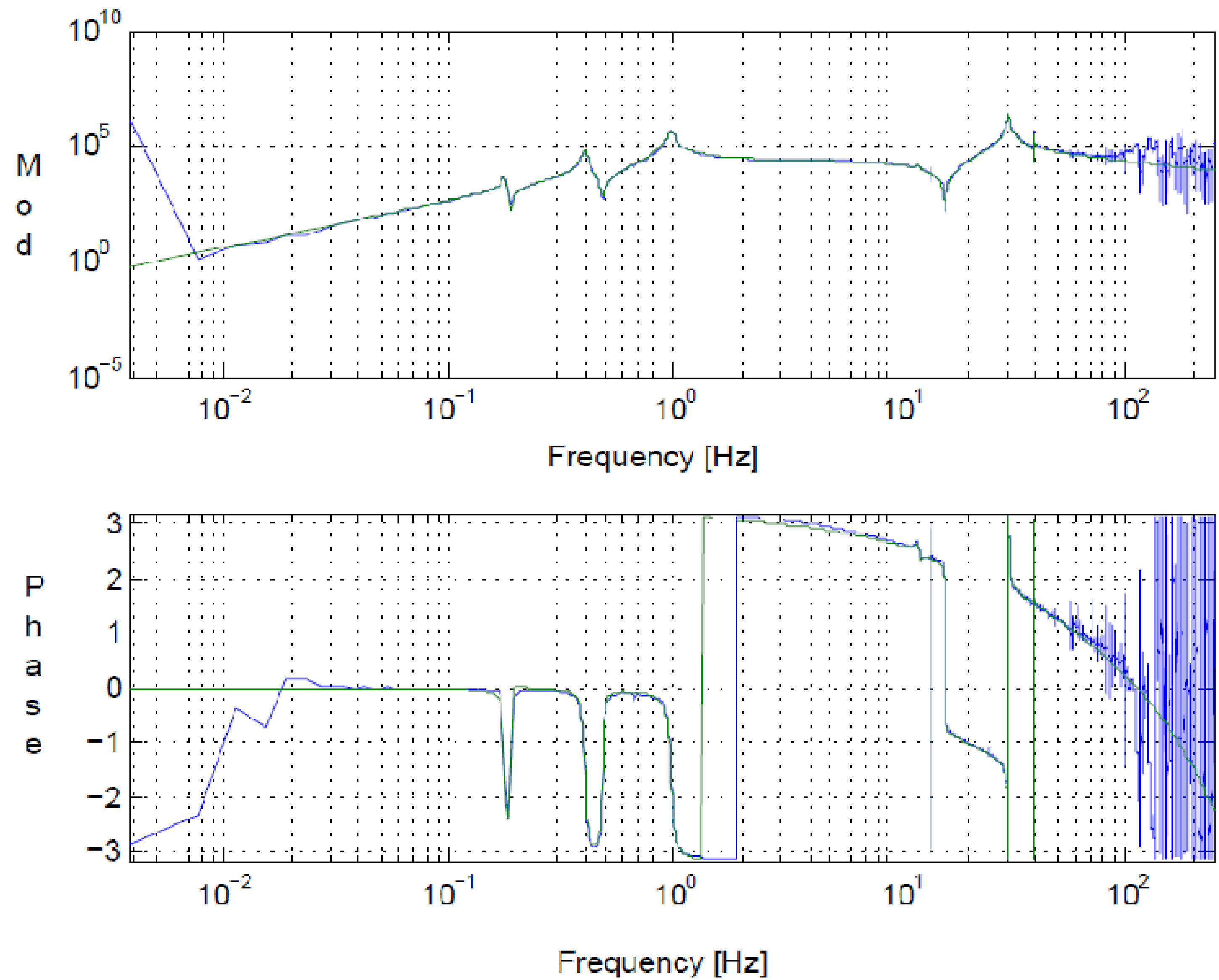
This plot shows the trasfer function measured by the Lvdt of 'F0'

The peaks are the resonances of the system

This TF is the Plant process (M)

This figure shows three peaks at low frequencies:

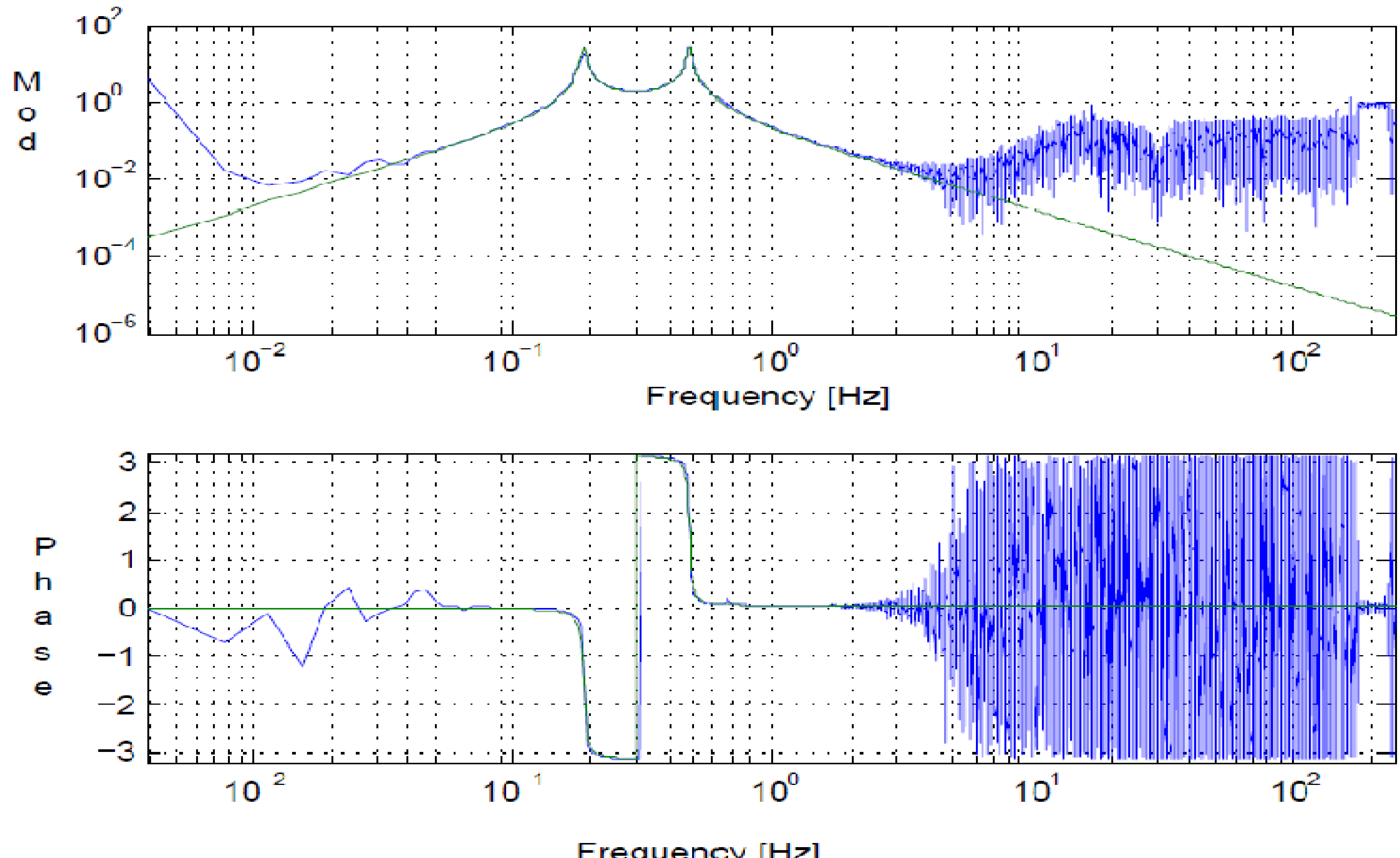
0.175mHz , 0.4005 mHz, 0.970mHz



In this plot is shown the transfer function measured by the accelorometers on the 'F0'

In this function there are the same structures at the low frequencies

Both plotted TFs are the responce of the crossbar '0' to vertical 'actuation'.



In this plot is shown the transfer function measured by the Lvdt on the F7, when the excitation comes from the Cr0.

This measurement is useful to rebuild the movement of F7 starting from F0

This reasoning is extendible at all pieces of the chain.

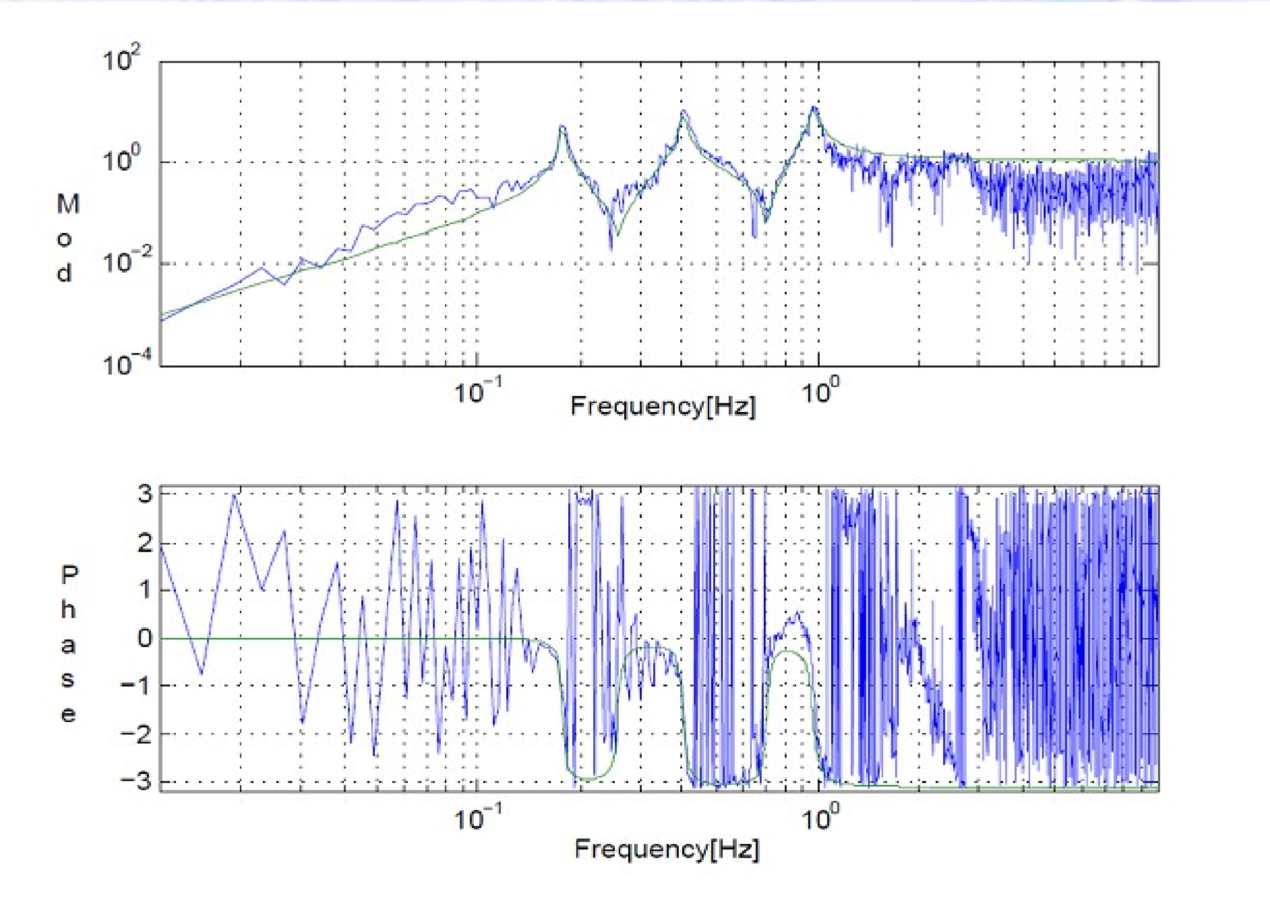
Background Signal

The background signal is caused by many factors, for example human activities, traffic, 'seism', ecc.

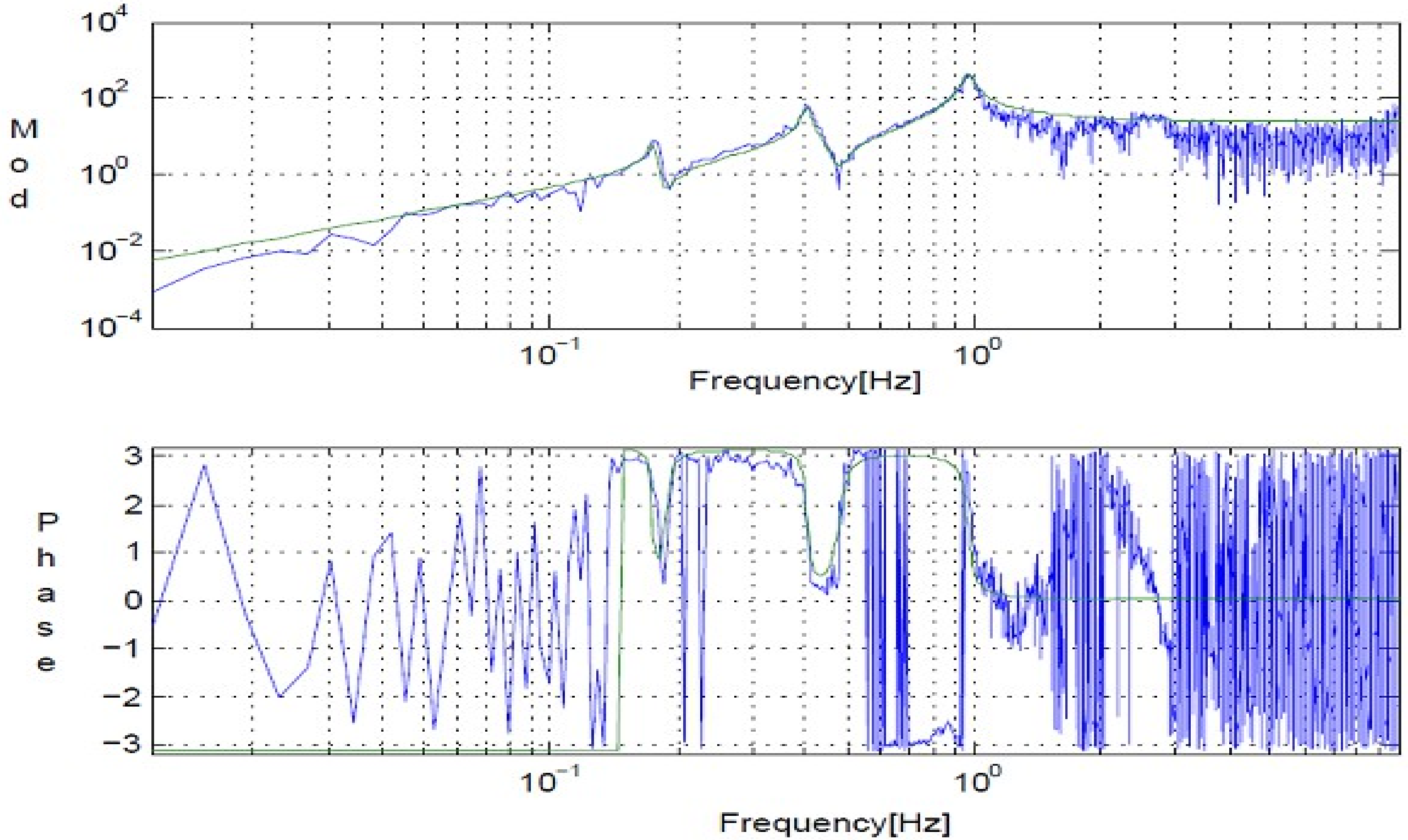
Its presence induces a motion of Virgo's suspensions

Its estimate is relevant to implementation of suspension control.

The measurement of the TF related to the background signal is necessary for correctly estimate of the suspension movement.



The Background signal
is mesaured
by the' seismograph' in the
Central Building (CB)
and in this plot
the TF between
 this sensor and the
Lvdt on F0 is shown



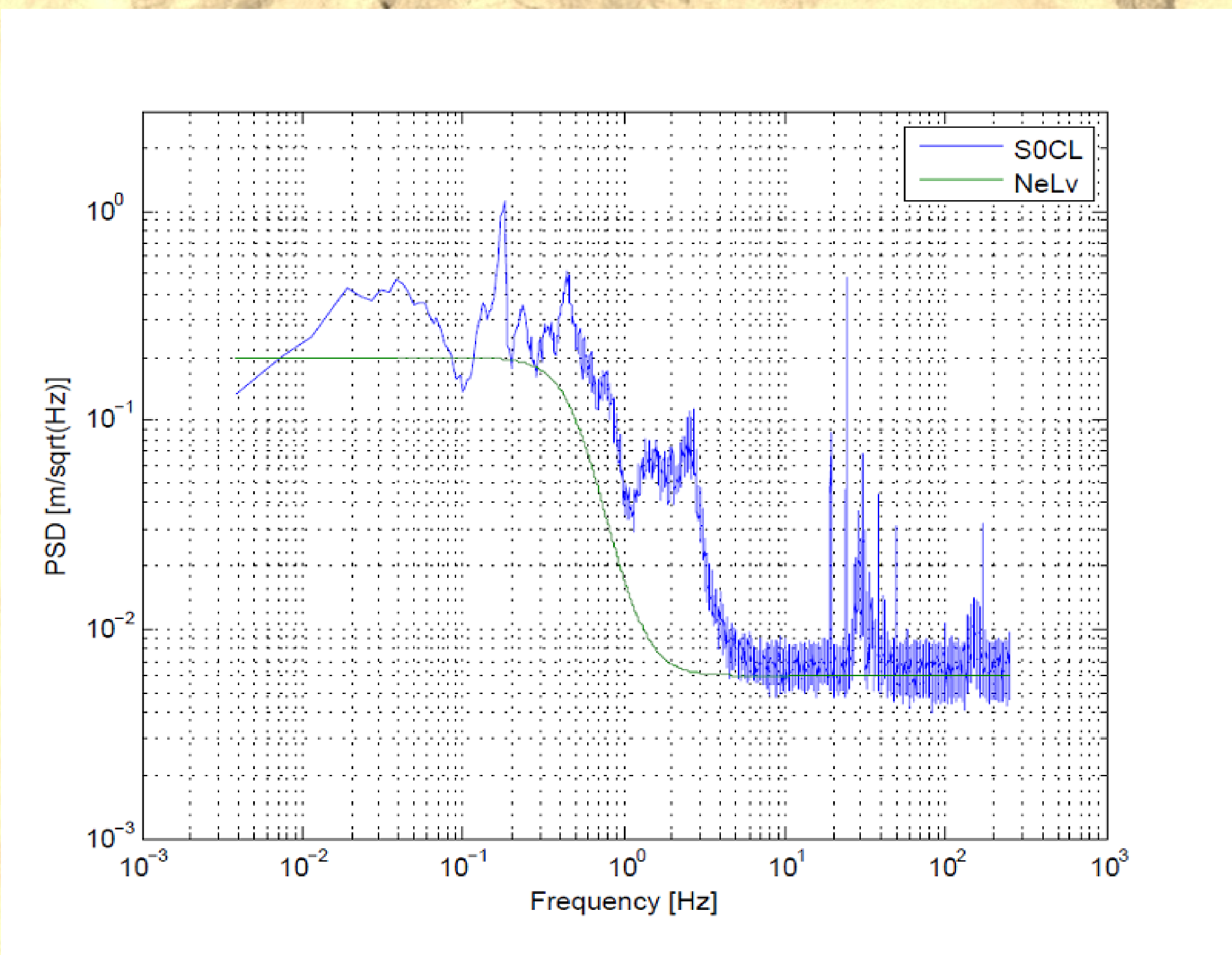
This function,instead, is the TF mesaured between the seismograph sensor in the CB
 and the accelometers on F0

Noise Budget

To implement this control, the knoweledge of noise of sensors and background noise is necessary .

Their indirect estimation can be made starting from the PSD of signals OL measured
By the LVDTs and the acceleorometers in open loop condition.

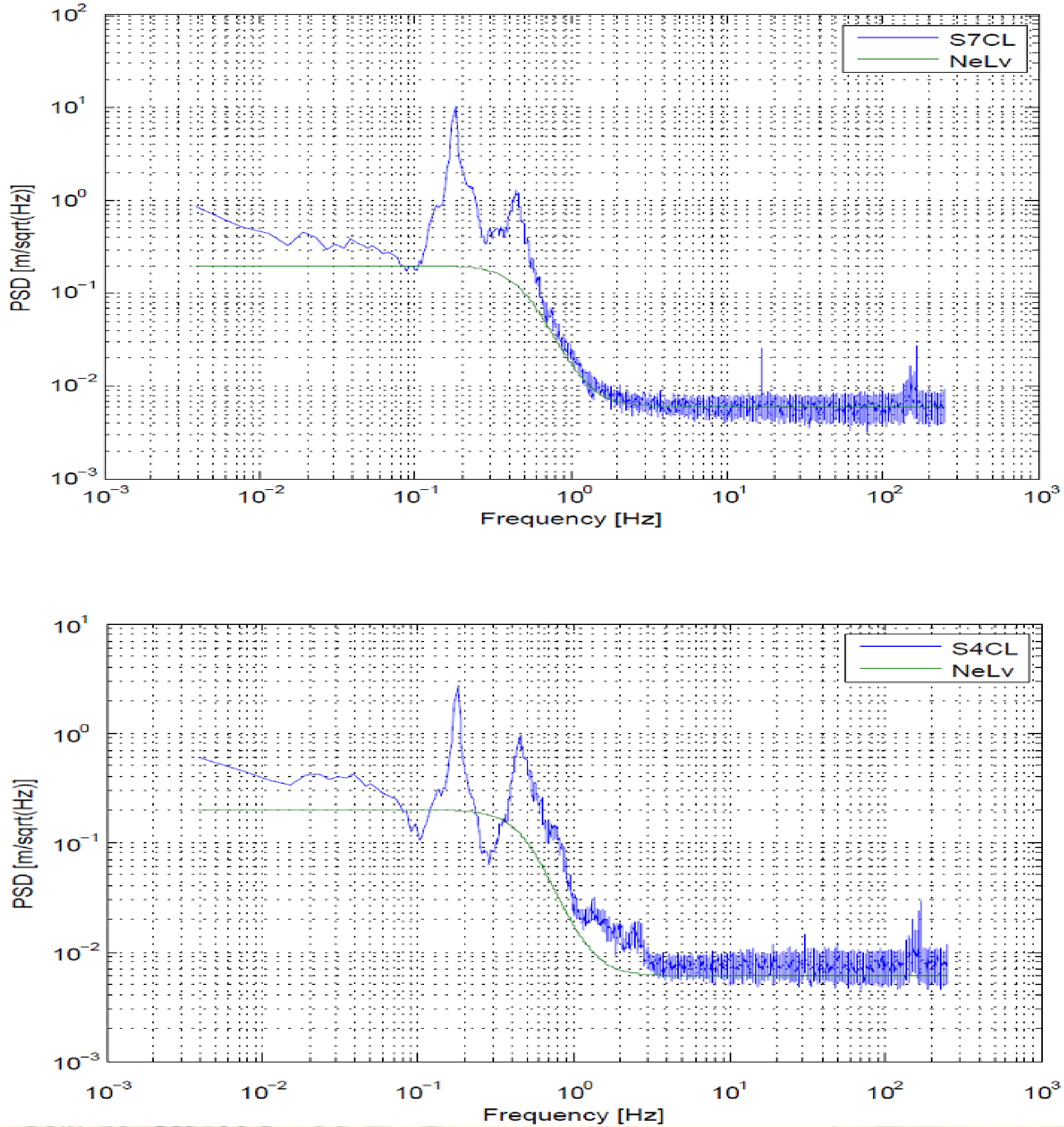
We have two possible sources of noise: Seism Electronics



The green line is the Electronic Noise of the LVDTs

At low and high frequencies we made the assumpion that the signal read on the Lvdt is soiled by electronic noise.

The region between [0.100,10] Hz is soiled with the background noise

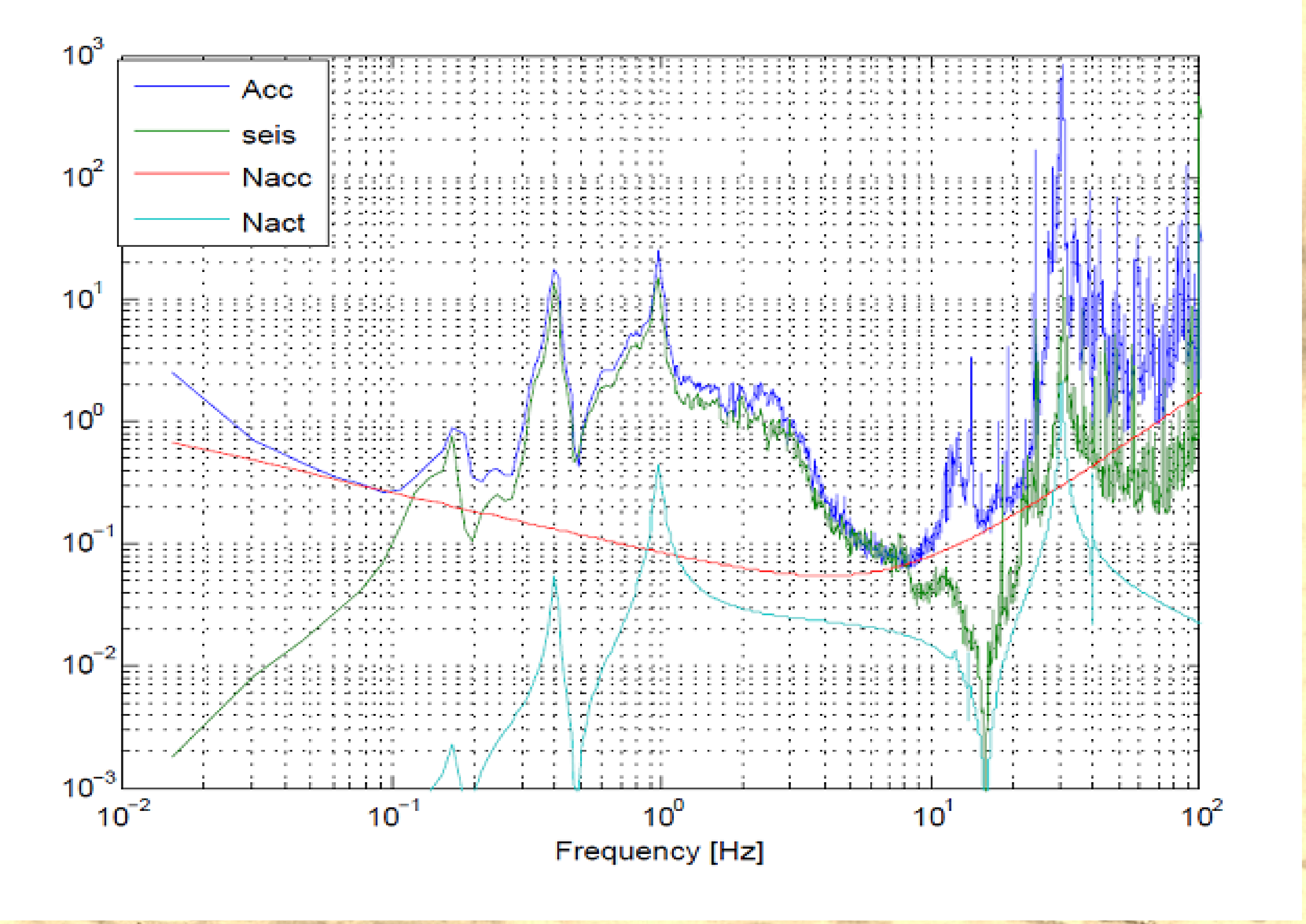


In these plots the PSD of F7, of F4 and its comparison with the electronic Noise for the sensor Lvdt are shown.

Noise budget: accelerometers

We have three possible contribution: Actuators Electronics Seism

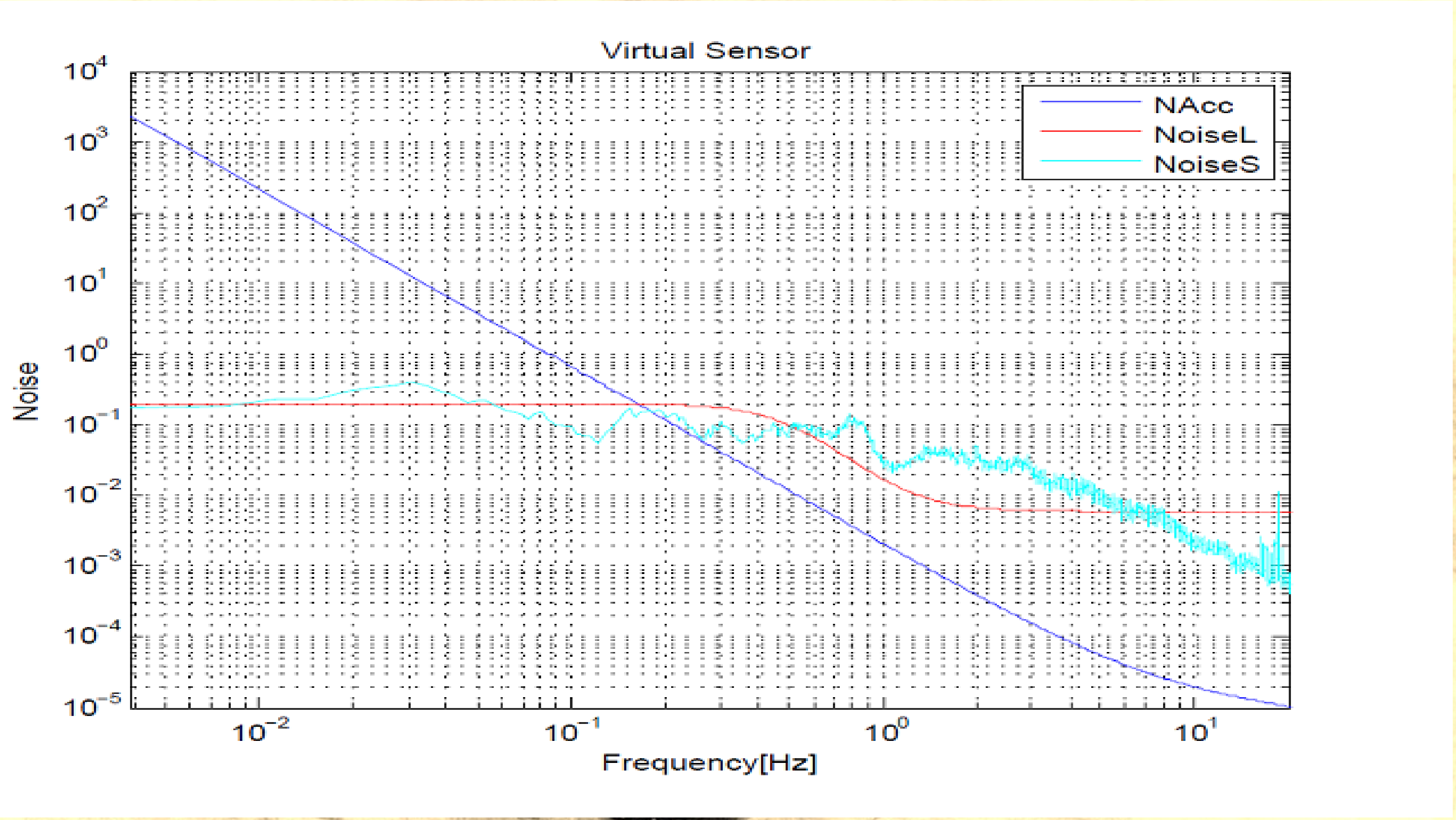
In this plot the comparison between SOL read by accelorometers on F0 (blu line),electronic noise (red line), actuator noise (turquoise line) and seismic contribution (green line) is shown.



The red line is related to electronic noise of sensor and its level is considered as 'upper limit' of the noise.

Important:

We are not ruled by actuator noise



This plot shows the comparison between the three noises .

At low frequencies we are ruled by Nacc..

HP filt

From few hundred mHz we are ruled by Electronic noise of Lvdt and background noise

LP filt

Virtual Sensor

Now, we are ready to define a virtual sensor; it help us to determine wich strategy HP/LP is effective,in order to lower the noise.

.

The signal read by this sensor is:

$$y = yLvLP + yAccHP$$

The noise of the Lvdt has two components:

Electronic noise **Ne**

Background noise **Ns**.

The accelorometer noise is assumpted to have this behavior:

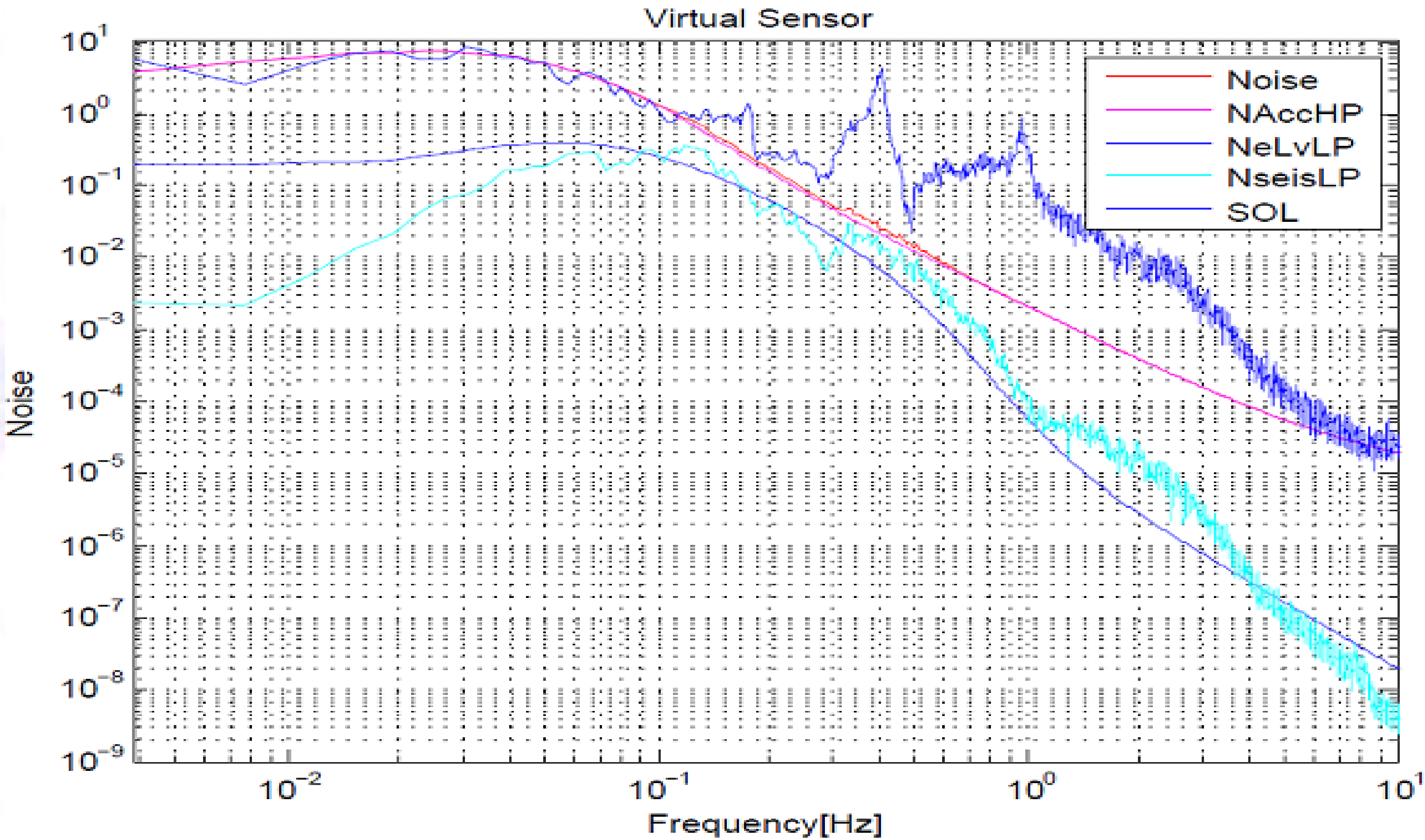
$$Nacc = \frac{f^{\frac{3}{2}}}{600} + \frac{1}{12\sqrt{f}}$$

In this sensor all noises are filtered and recombined in a new variable.

After, these noises are filtered and recombined in this way:

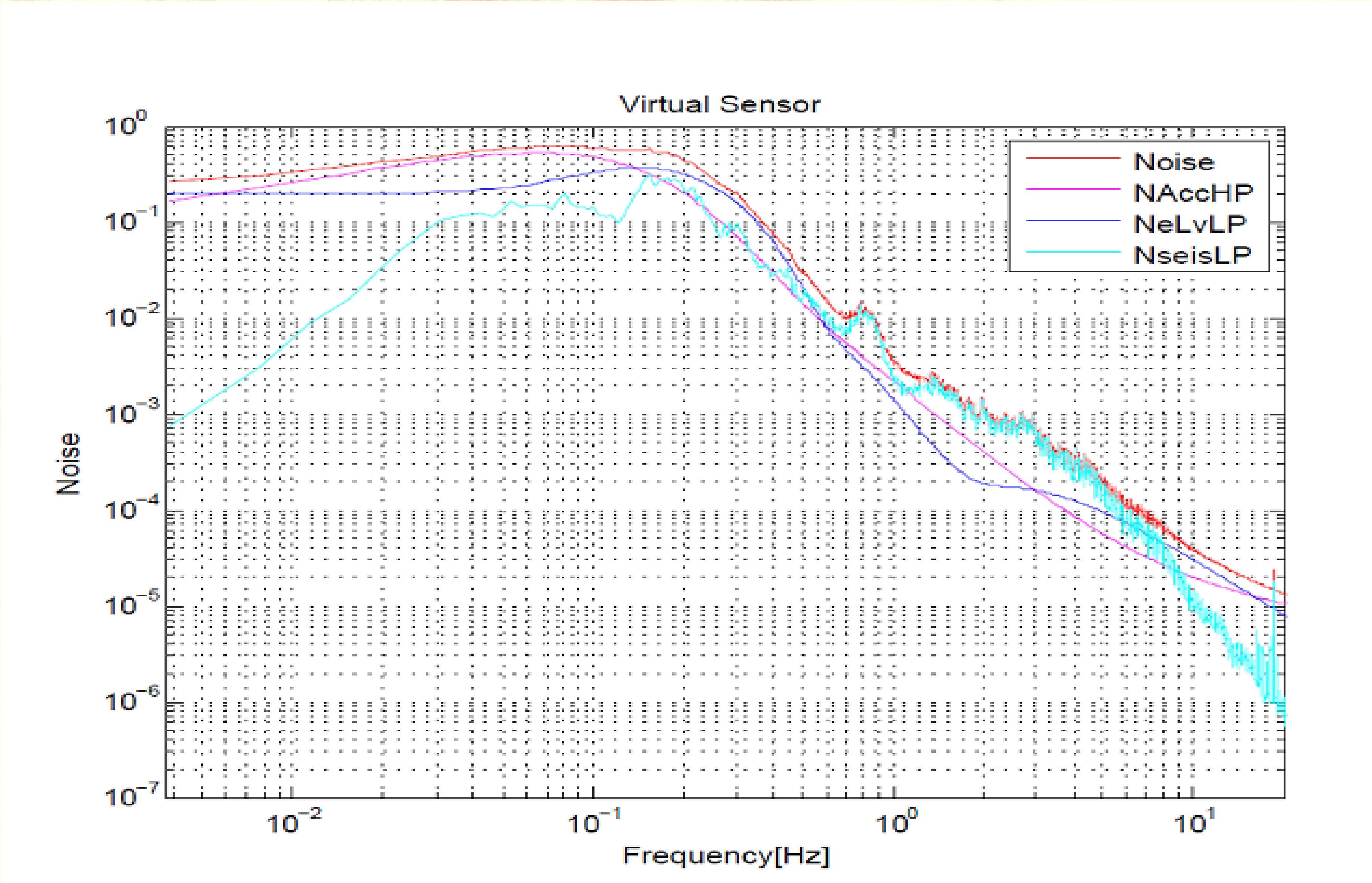
$$Noise = \sqrt{(NaccHP)^2 + (NsLP)^2 + (NeLP)^2}$$

This PSD are given in units of dispalcement.

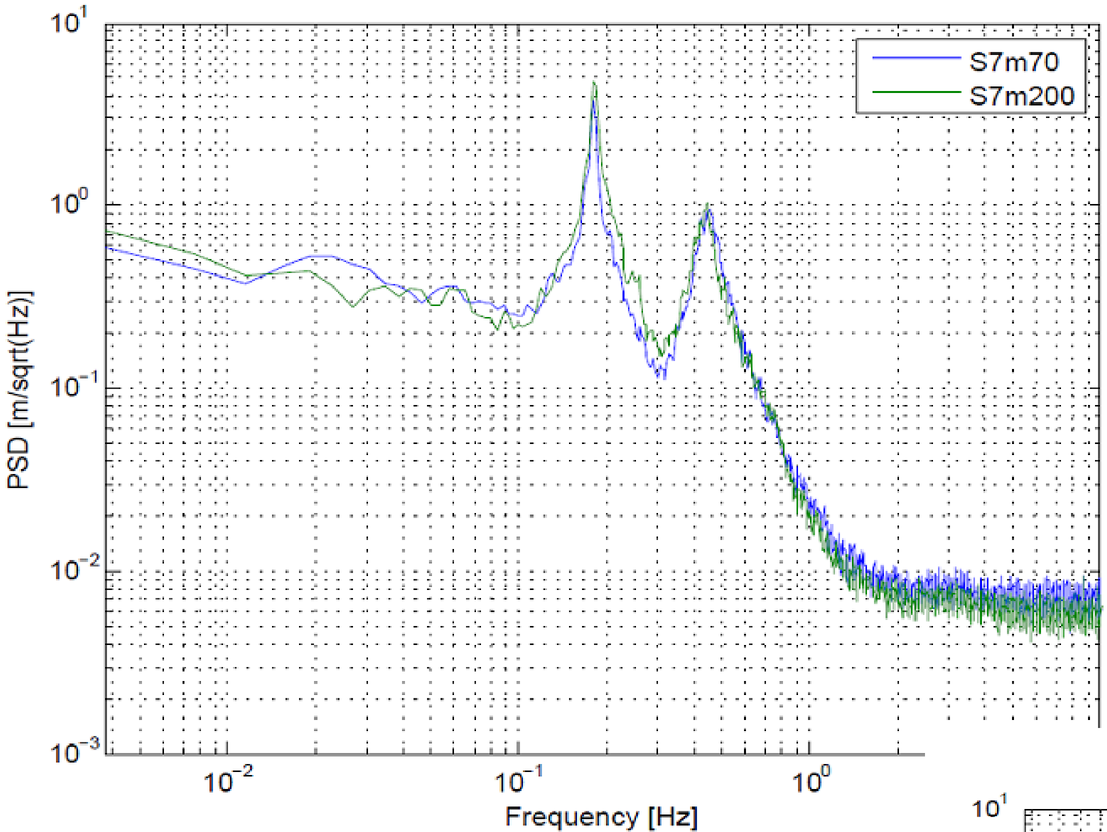


In this plot the effect of the filtering of the noises are shown

We show the the effect of some strategy HP-LP



In this plot the effect of filters HP and LP of the strategy 200 mHz on noise of the sensors and their recombination in the variable 'Noise' are shown.



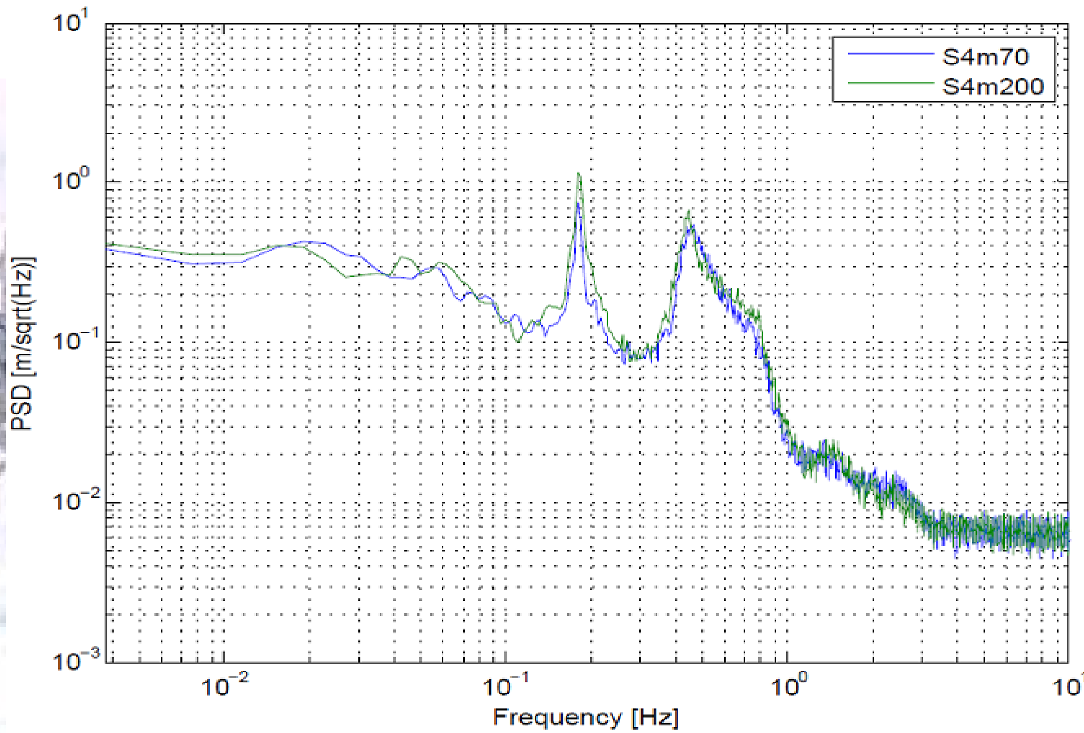
Another important check, to determine which strategy improves the filtering, is the comparison between signals read by the Lvdts on other filters.

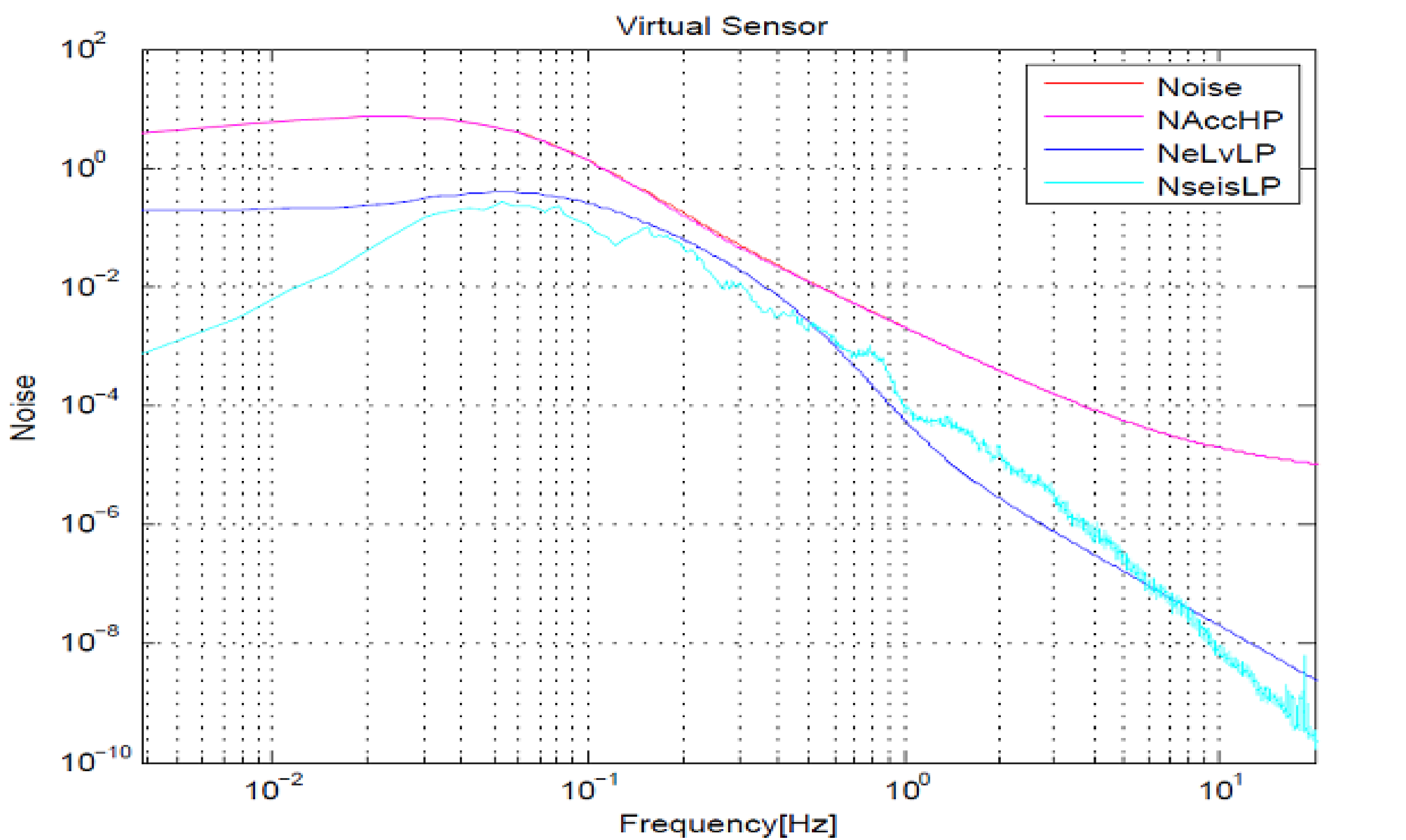
In these plots, the comparison between the mesaurement of S4 an S7 in two different stategies, are shown.

The green line is related at strategy 200 mHz

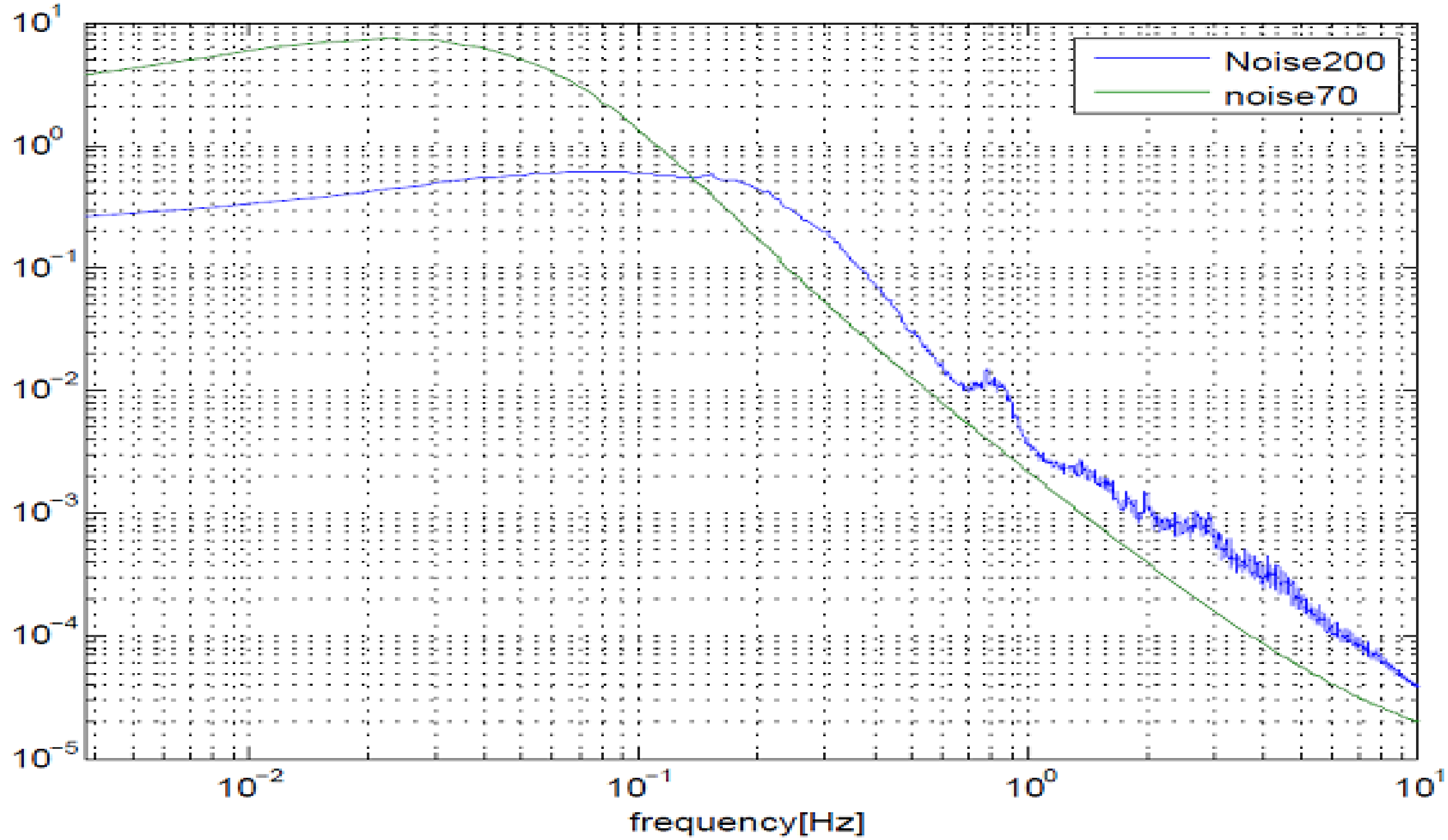
The blu line is related at strategy 70 mHz

We conclude that the better stategy is the '70 mHz'





In this plot the effect of filters HP and LP of the strategy 70 mHz on noise of the sensors and their recombination in the variable 'Noise' are shown

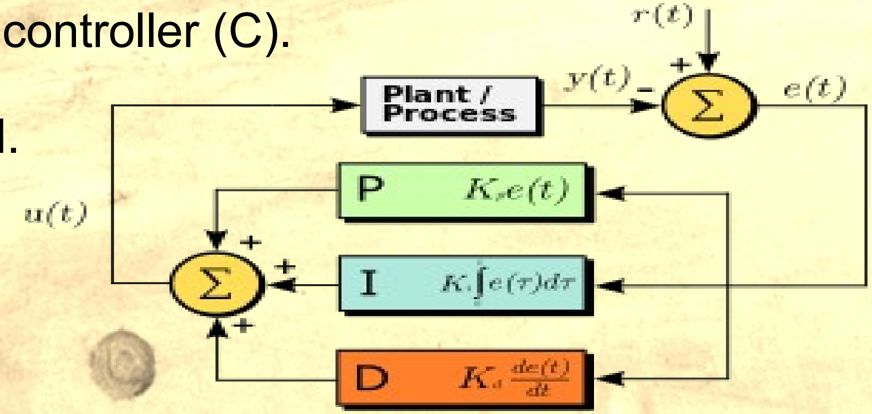


In this plot the effect of two strategy HP and LP on Noise is shown.
The green line is related to strategy 200mHz,instead
the blu line is related to strategy 70 mHz.

Lowering the crossover frequency, we can see an improvement of the filtering on the background noise ,and a degradation of the filtering in low frequency .

PID Controller

We used, to implement the verical control, a PID controller (C).

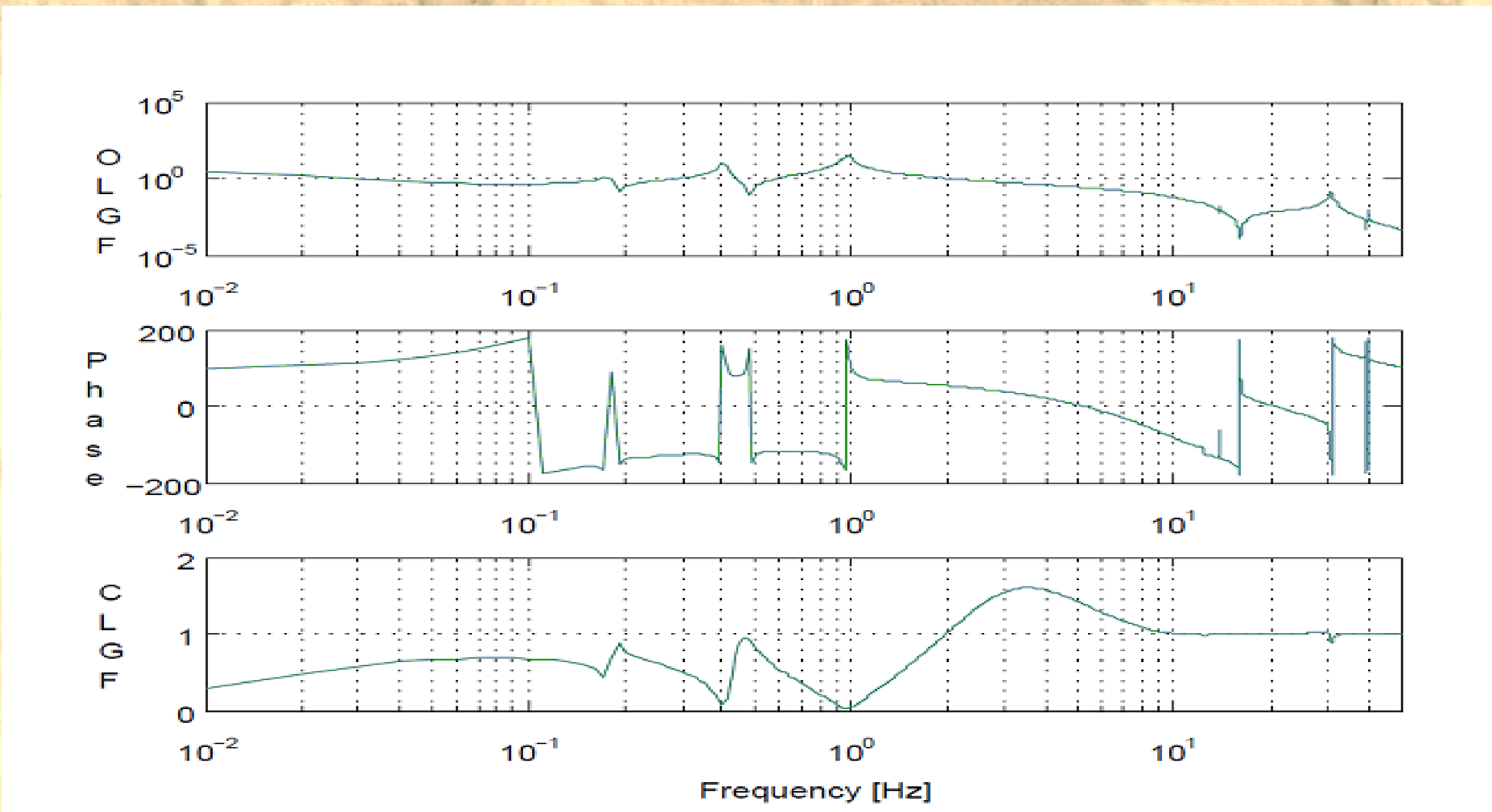


The control loop is closed on the plant process M.

In this configuration the CLGF is:

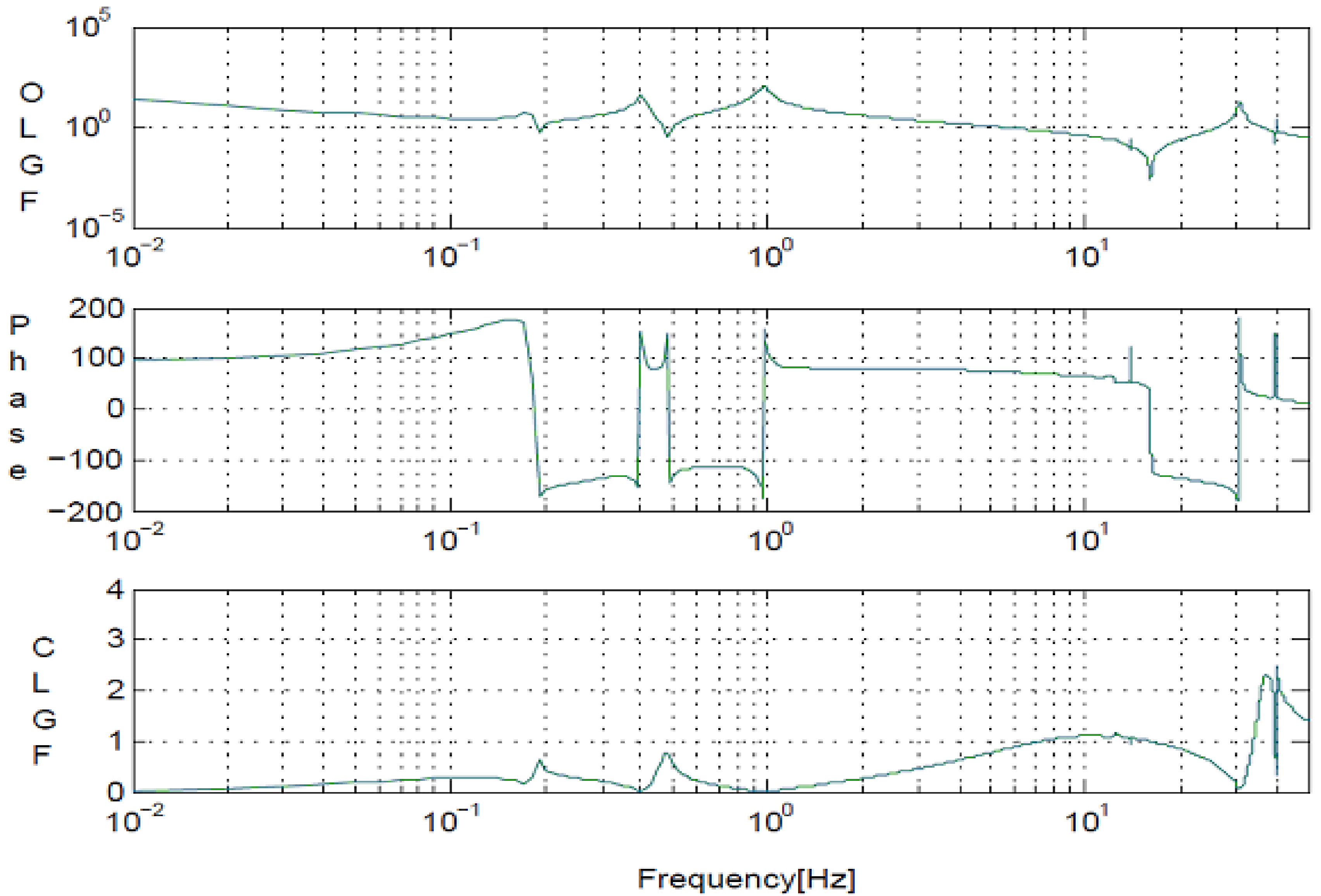
$$CLGF = \frac{1}{1 - MC}$$

Very important point is the stability of the controller.



In this plot the action of Pid controller (Cinit) (gain 0.0030 at 1 Hz) is shown

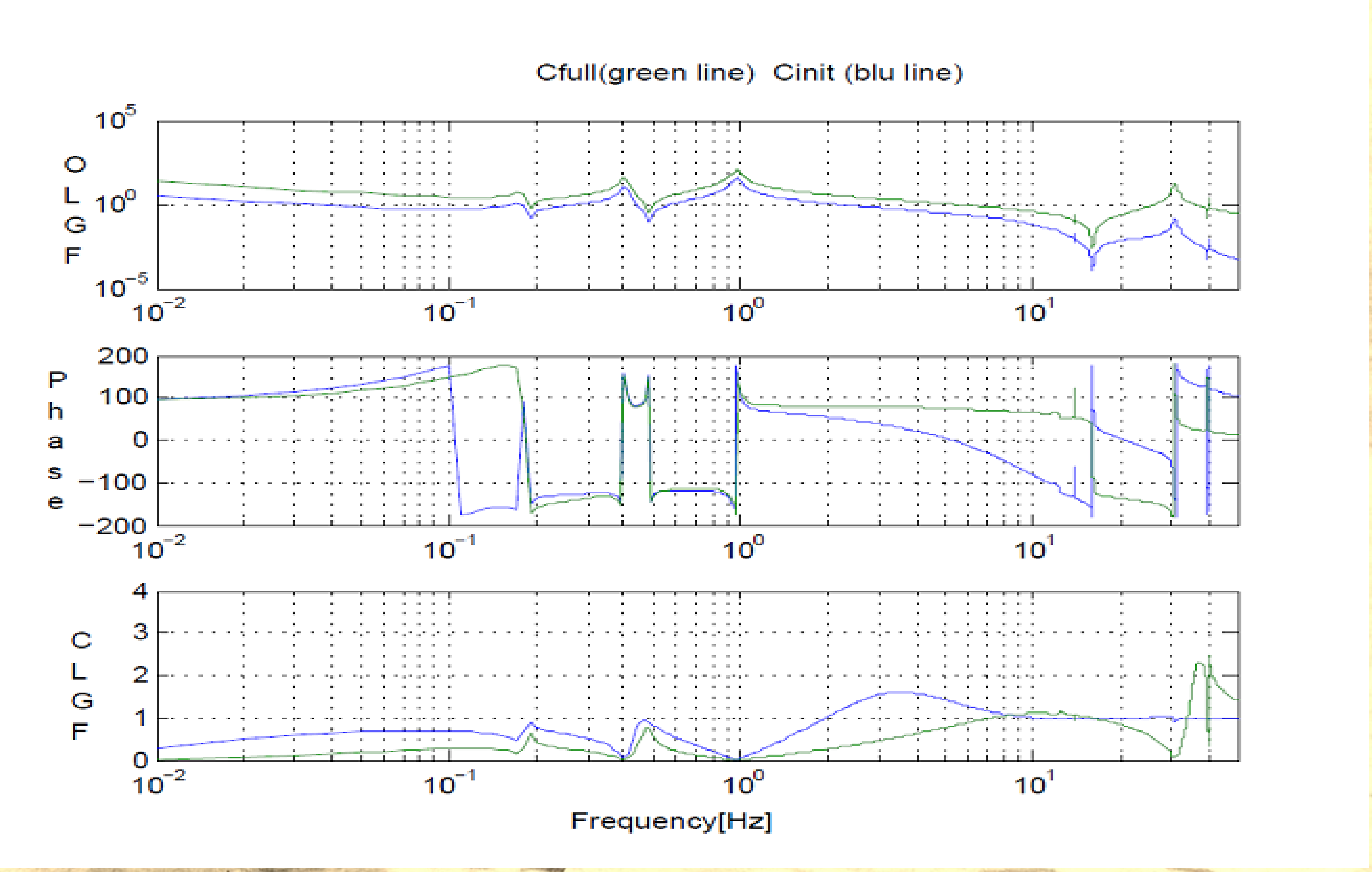
We can see that Cinit is a stable Controller.



In this plot the action of Pid controller (Cfull) (gain 0.0100 at 1 Hz) is shown

We can see that Cfull is a stable Controller.

In this plot, the comparing between the controller Cinit and Cfull, is shown

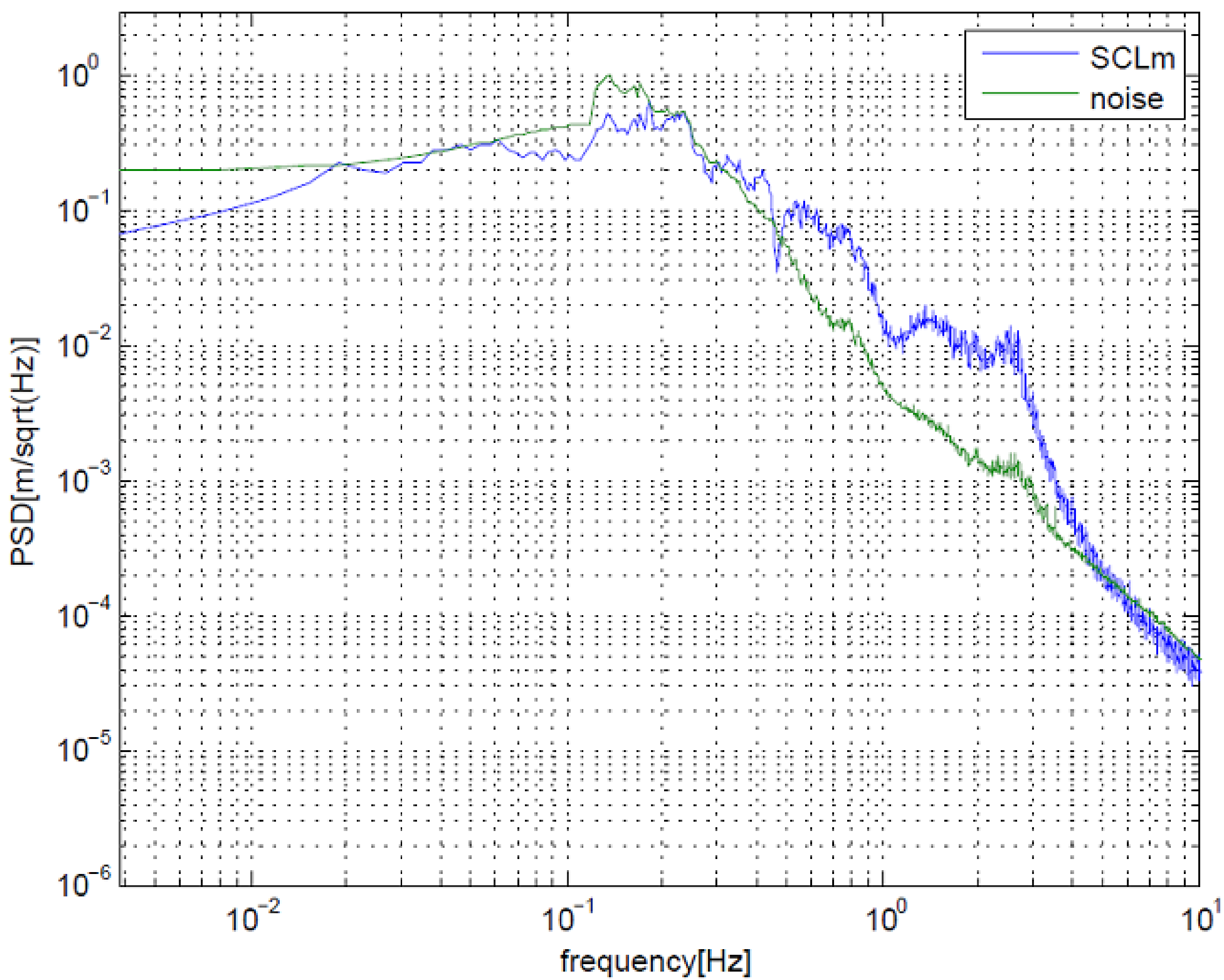


Performace analysis

We begin our anlisys plotting the signal closed loop for two different strategies.

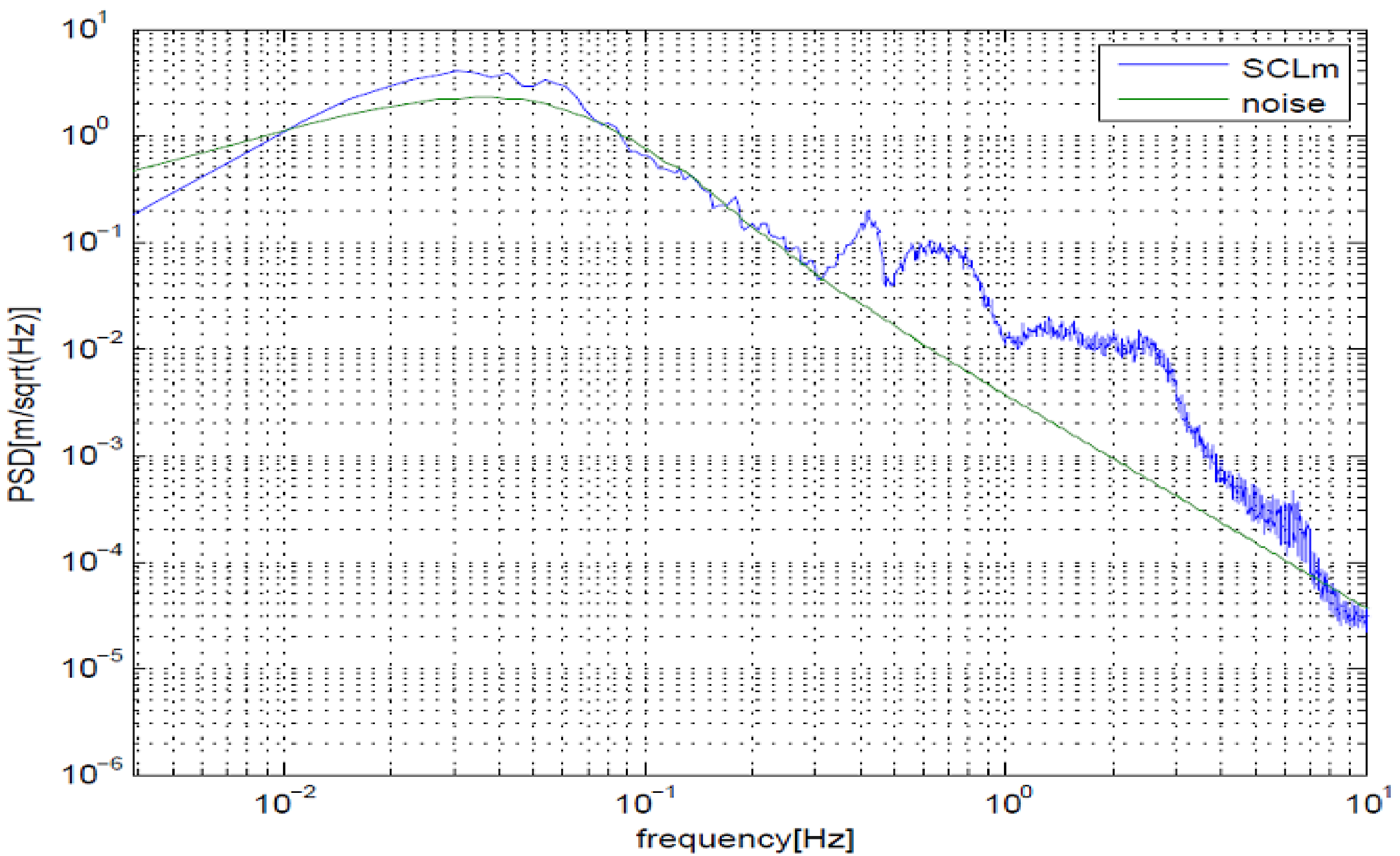
- Strategy 1: HP-LP 200 mHz
- Strategy 2:HP-LP 70 mHz

This comparison is made with the mesaured SCL



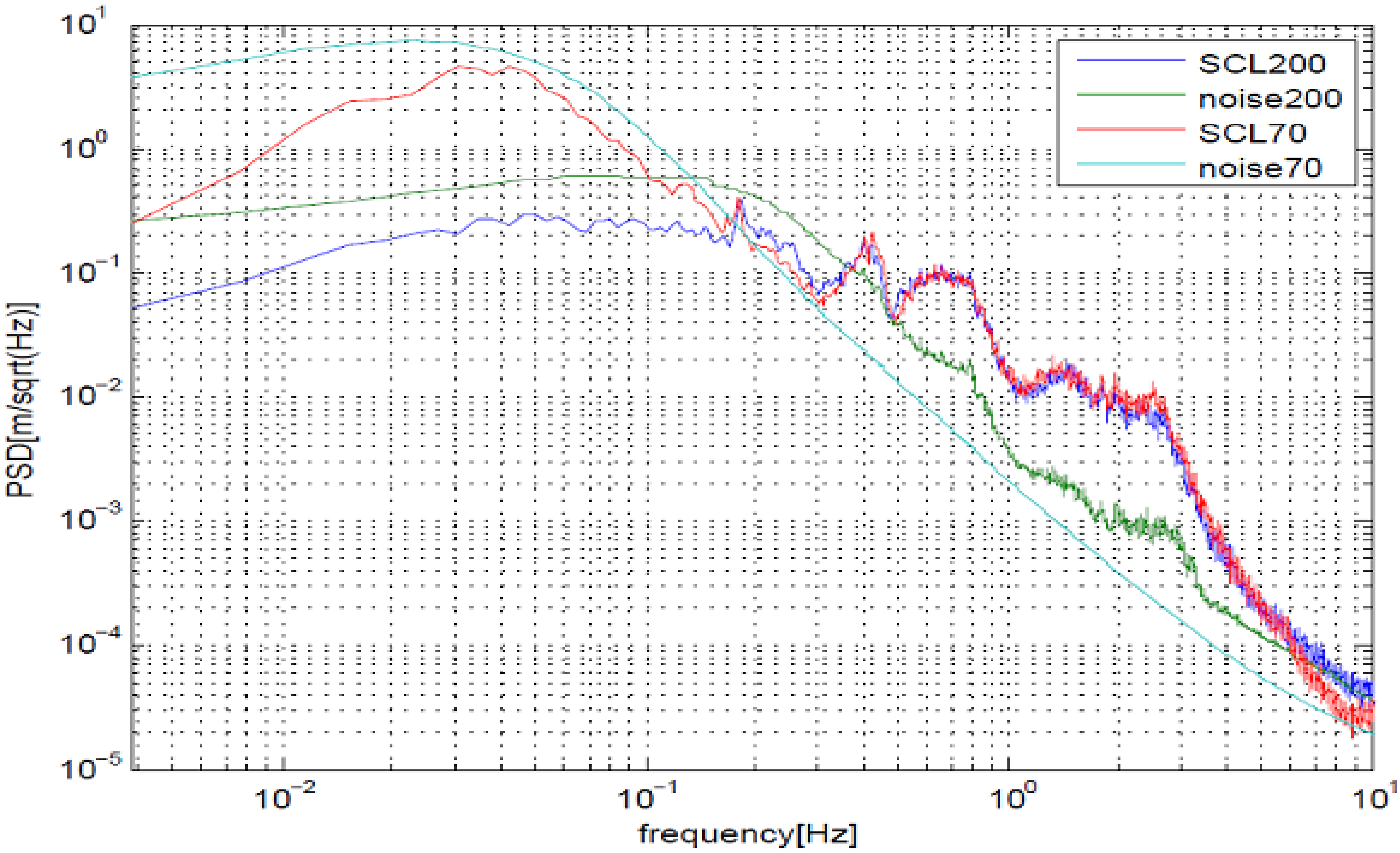
In this plot, the closed loop signal measured with strategy 200 mHz and its comparation with noise level, are shown.

Controller Cinit

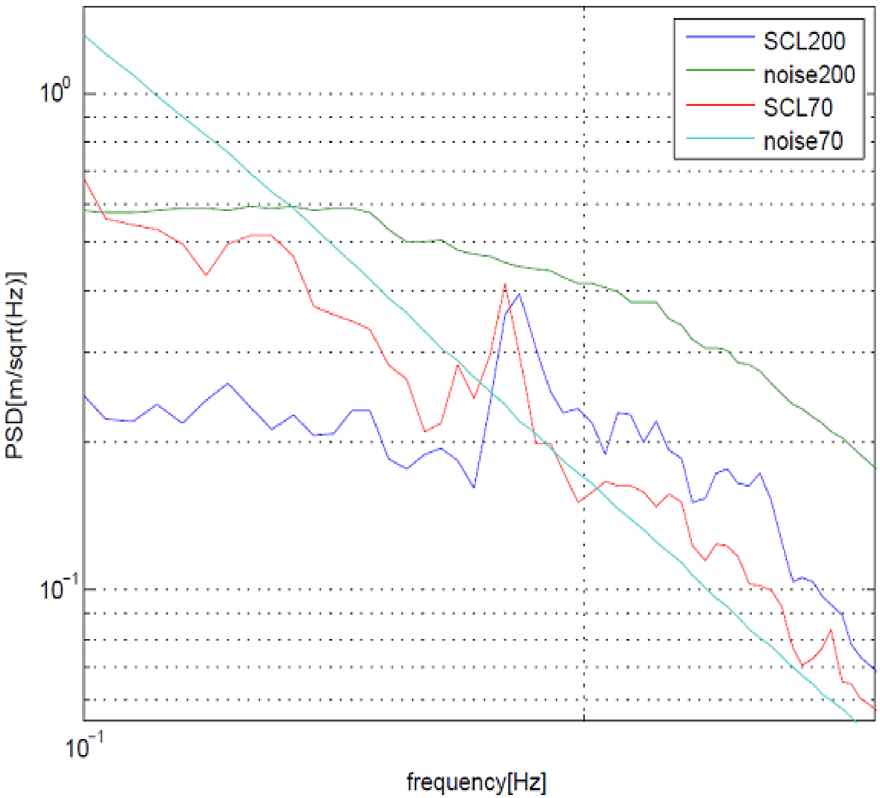


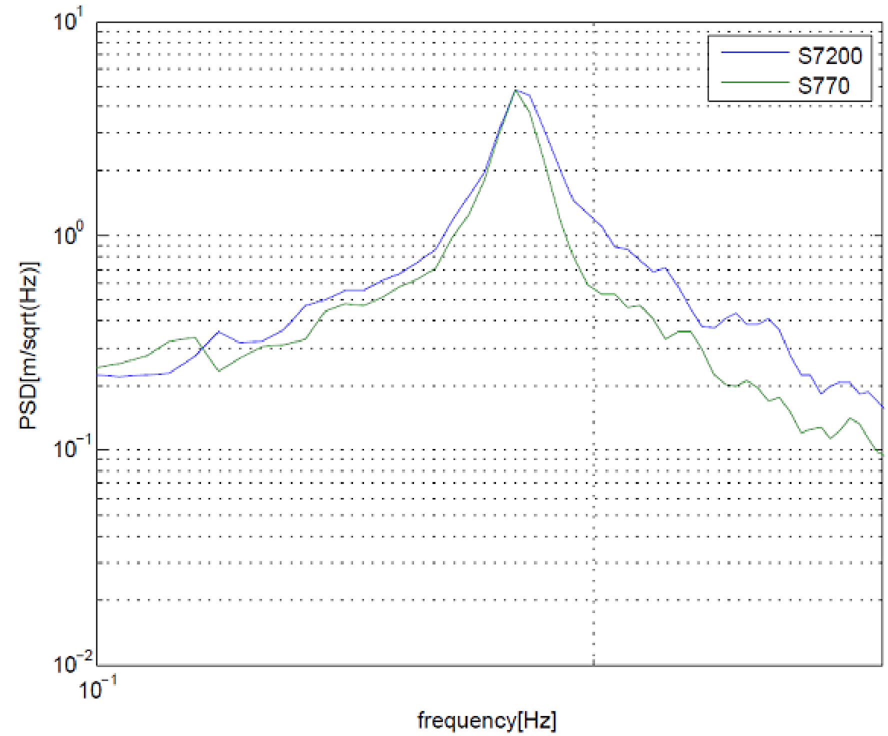
In this plot, the closed loop signal measured with strategy 70 mHz and its comparation with noise level, are shown

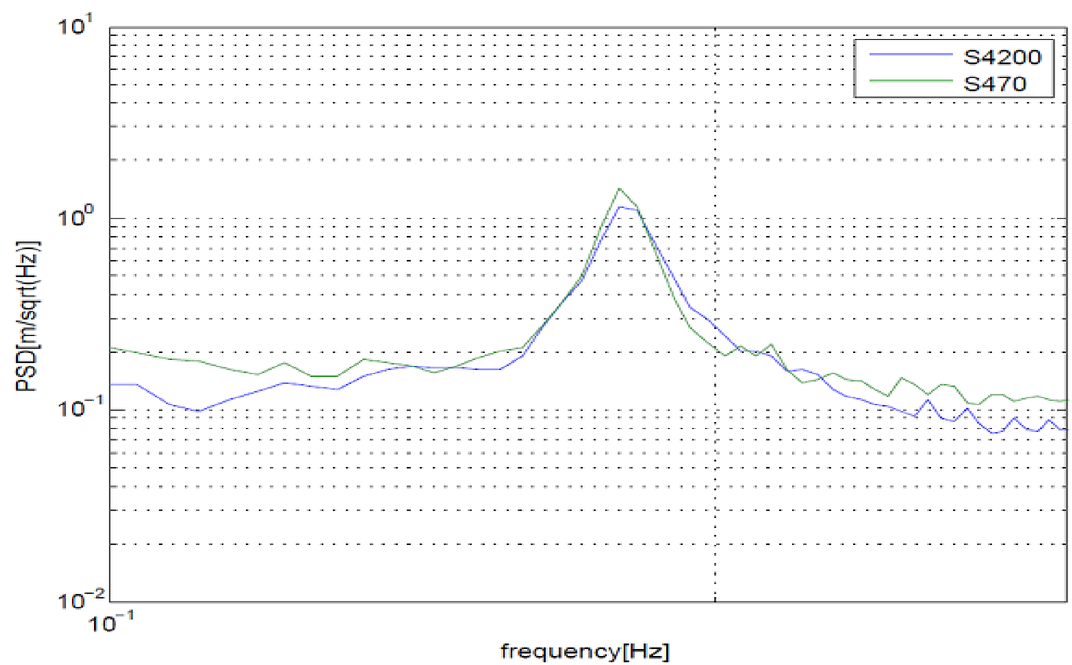
Controller Cinit



In this plot, the comparison between the mesaured SCL and respective noises in two different stategies are shown.

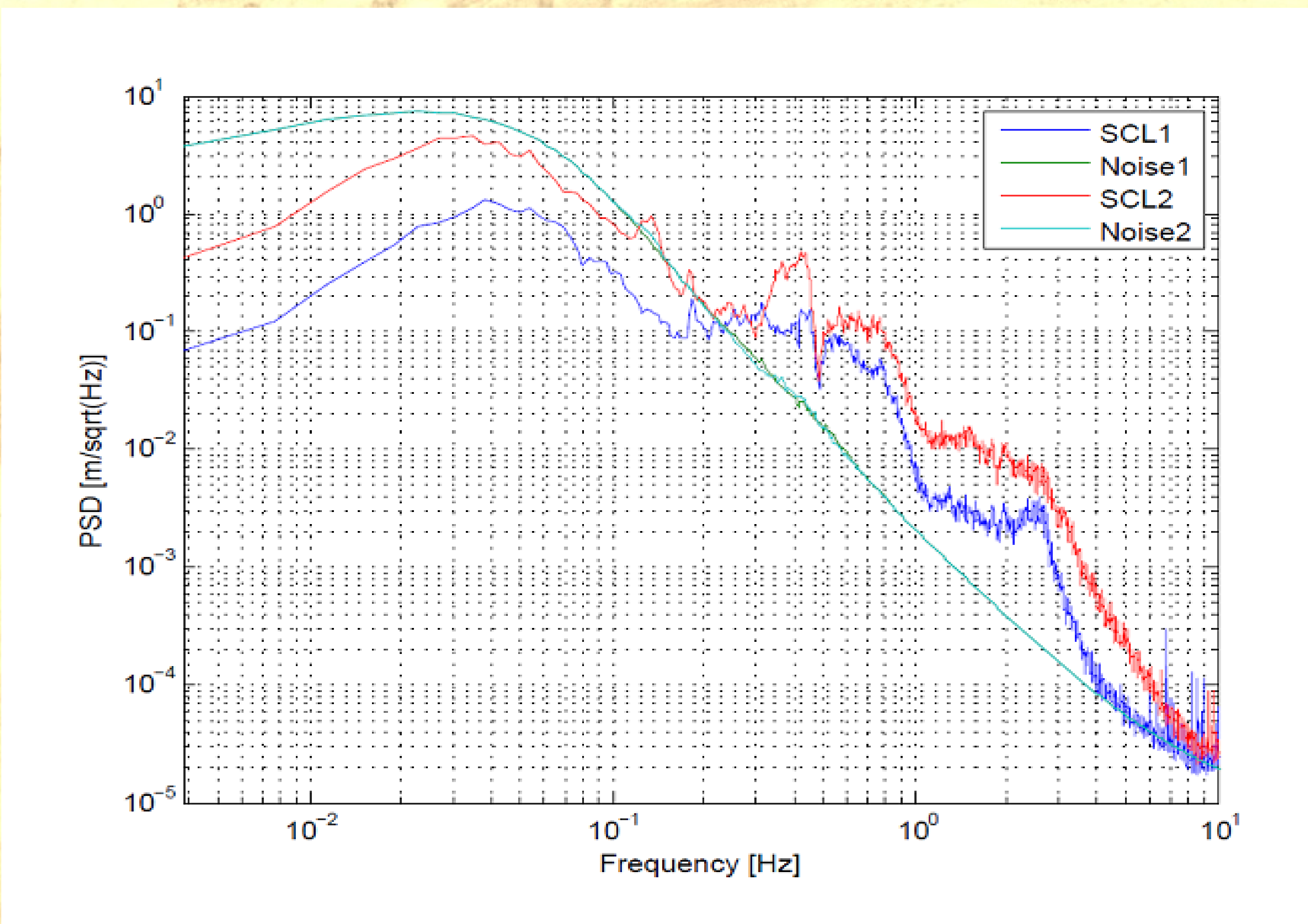






We conclude that the better stategy is the '70 mHz'

To test the real performances of the controller Cfull, we close the loop on it .
We compare this closed loop signal and the closed loop signal whit Cinit

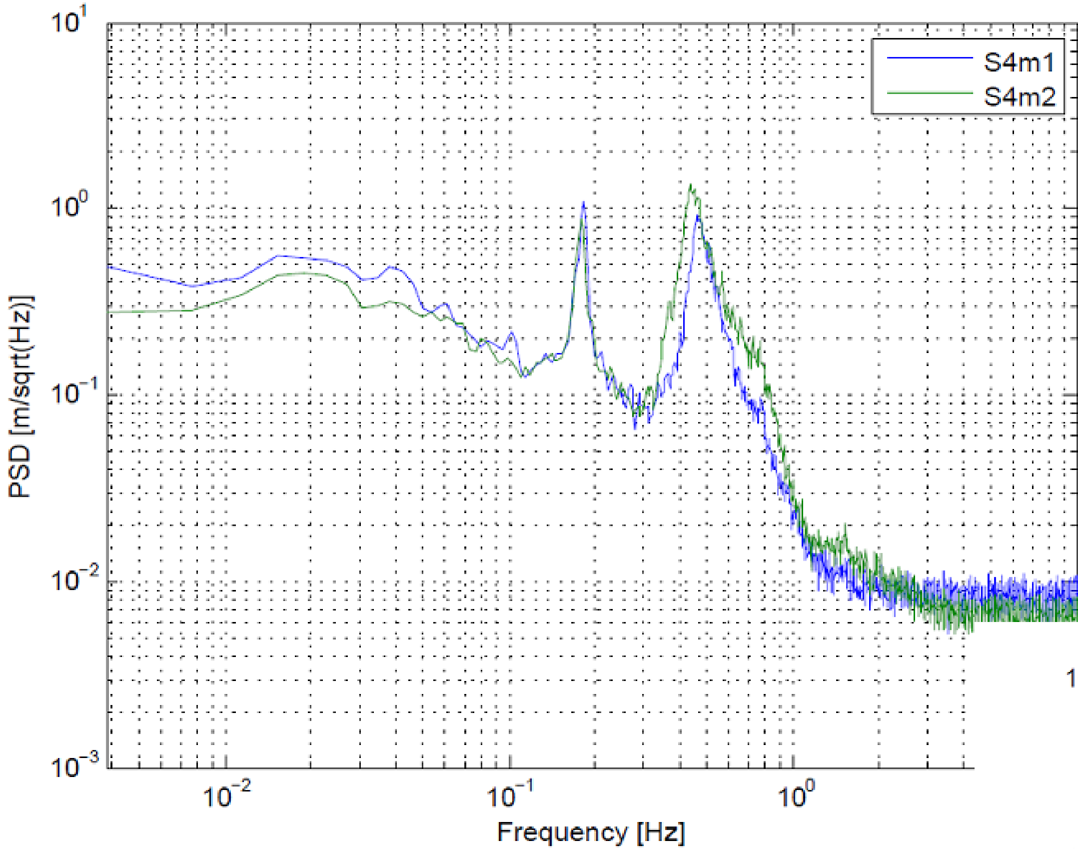


This plot shows the signals closed loop and respective noises

The red line is related at the controller Cinit

The blu line is related at the controller Cfull

In the range [0.180,3] Hz we have an improvement of the SCL with the controller Cfull.



we examine the signals
S4 and S7

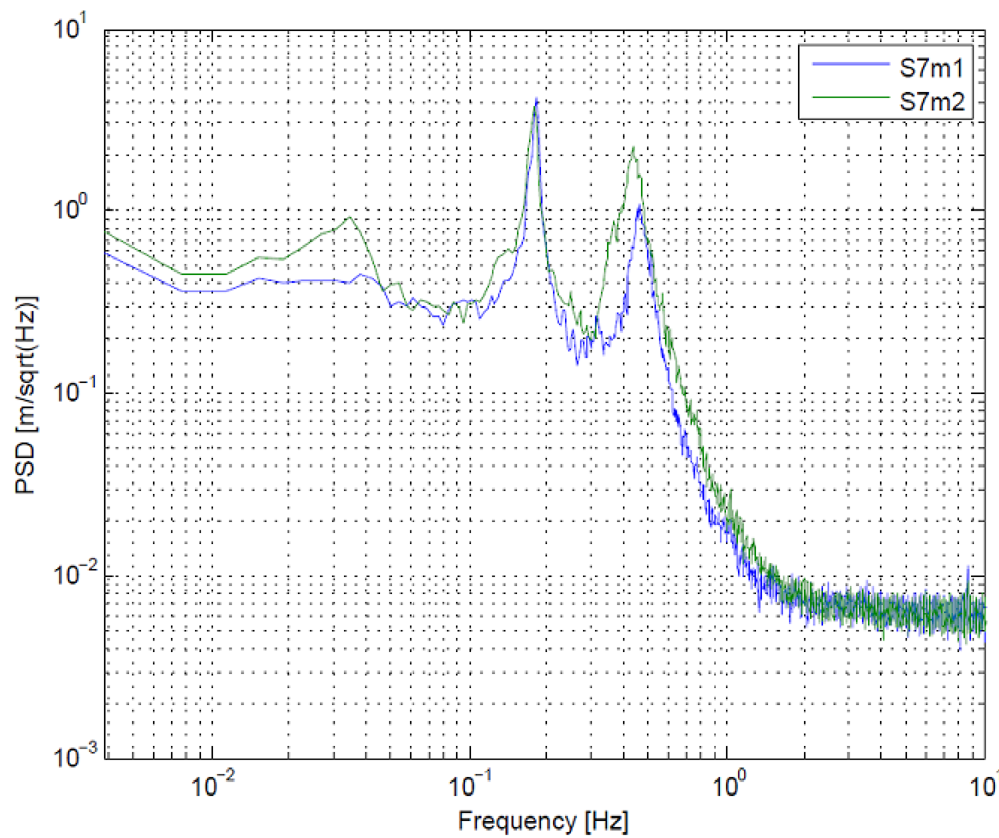
This check is very important because it
help us to better understand
the performance of the controller

The green line is related to the controller
Cinit

The blu line is related to the controller
Cfull

In this case, as we saw, we have
an improvement in the **range [0.180,3] Hz**

We can see this improvemet
on the second peack.



Seismic Data

Seimic excitation could be different. These differences could be seen, in the range of low Frequencies, in some period of the year.

Starting from the seismic excitation, we can have an estimate of the movement of the suspension, in different background conditions (SOLr).

This data is useful to develop a tool that help us ,vitually ,to analize the behavior of the control strategy.

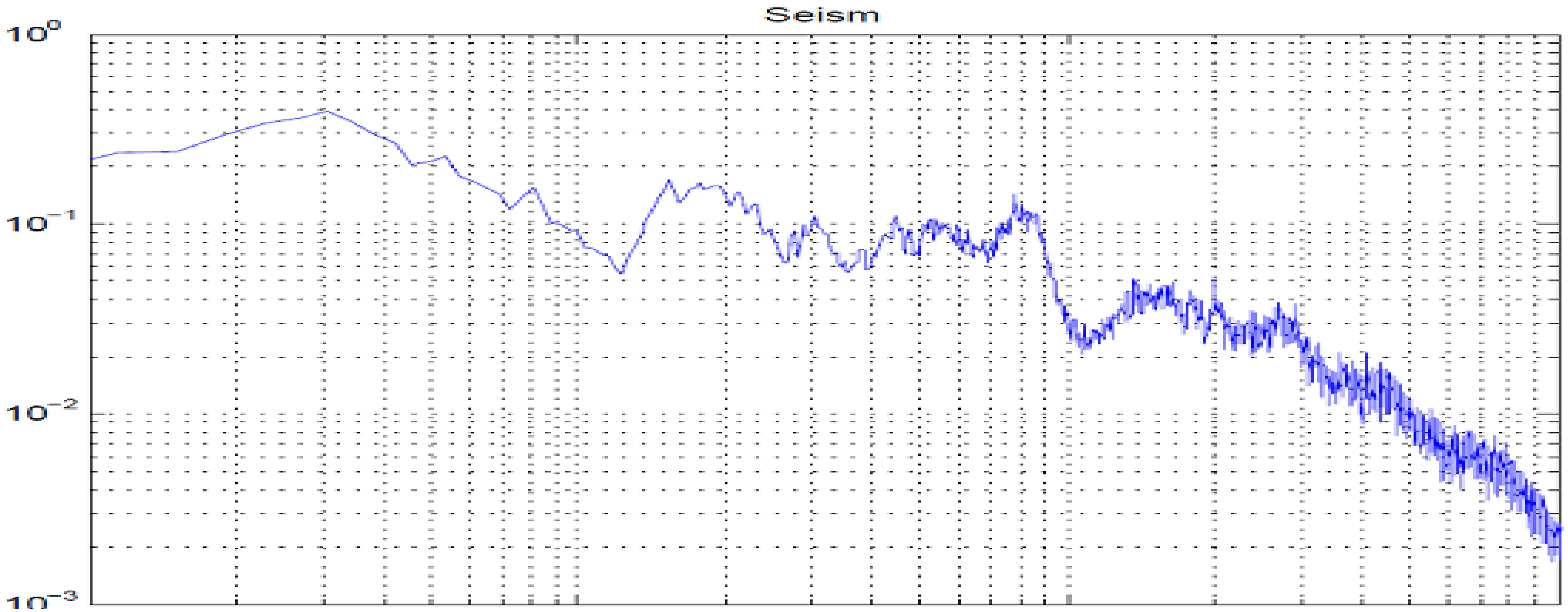
Closing the control on SOLr, in a particular background condition:

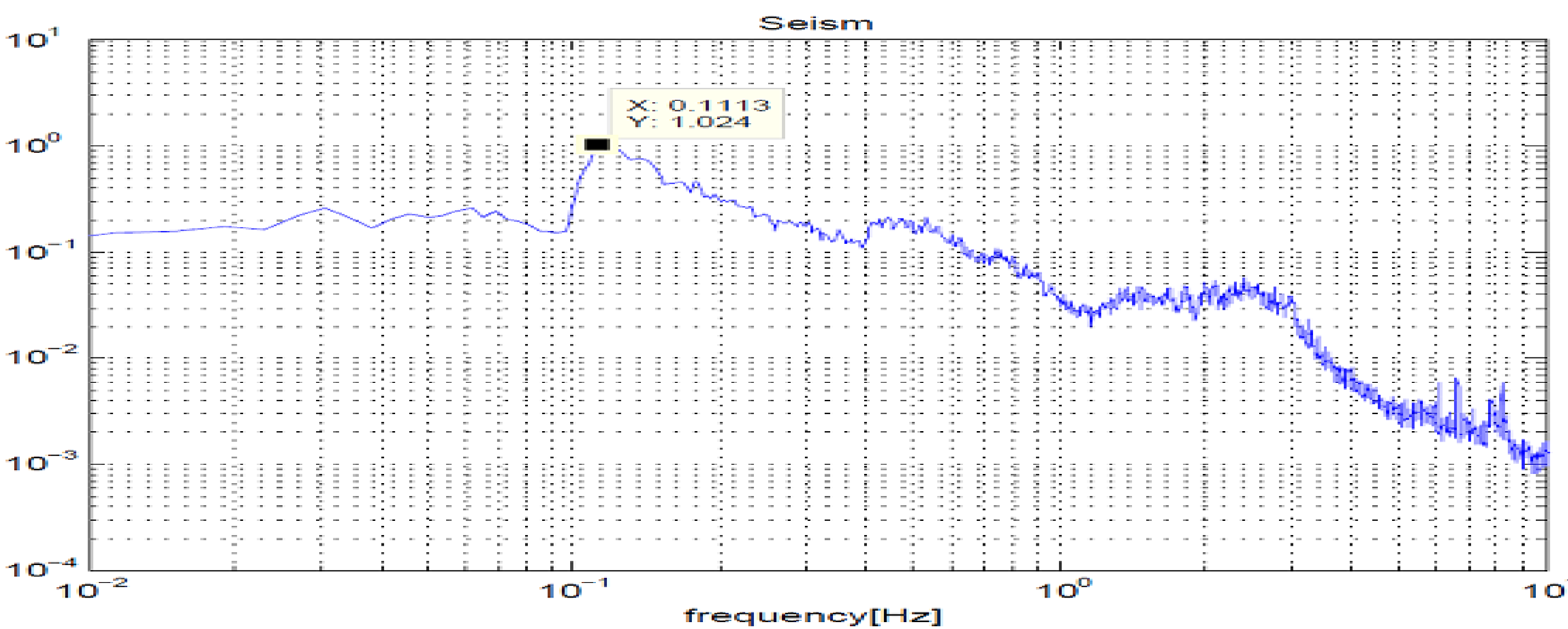
1)we can predict the behavior of the signal CL with different strategies HP/LP

2) we can analize the performance of the selected controller.

3) we can improve the control strategy for a particular seismic excitation.

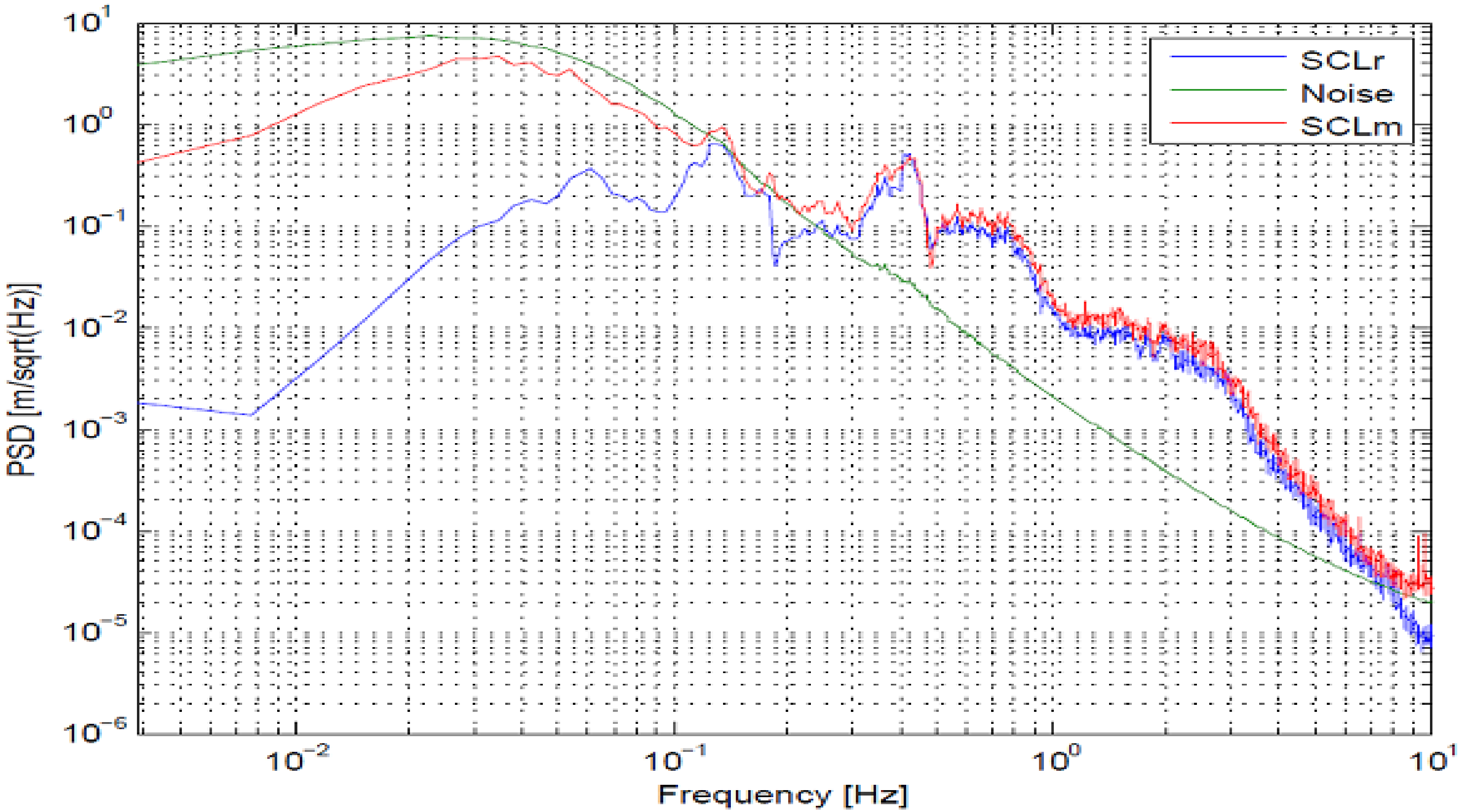
Next, we can see some example of the diffrent seismic excitation and an application of this tool.


Seism
10^0
10^-1
10^-2
10^-3


Seism
10^1
10^0
10^-1
10^-2
10^-3
10^-4
X: 0.1113
Y: 1.024
10^-2
10^-1
10^0
10^1
frequency[Hz]

In this plot , the comparison between the SCLm and SCLr is shown (strategy 70 mHz)

We can see that, is a good tool to reproduce the real data.



OCTOPUS DATA

We can produce the same results using the simulations of OCTOPUS (VIR-501A-09).

OCTOPUS is a frequency domain model for simulating the mechanical systems
Mechanical systems are represented in terms of the Transfer Functions.

In particular, OCTOPUS is used to simulate the TFs of the suspensions.

Changing the value of some parameters of our system, as the stiffness of F0, we produce a
a new system.

The aim of this simulation is to produce SCL related to different mechanics.

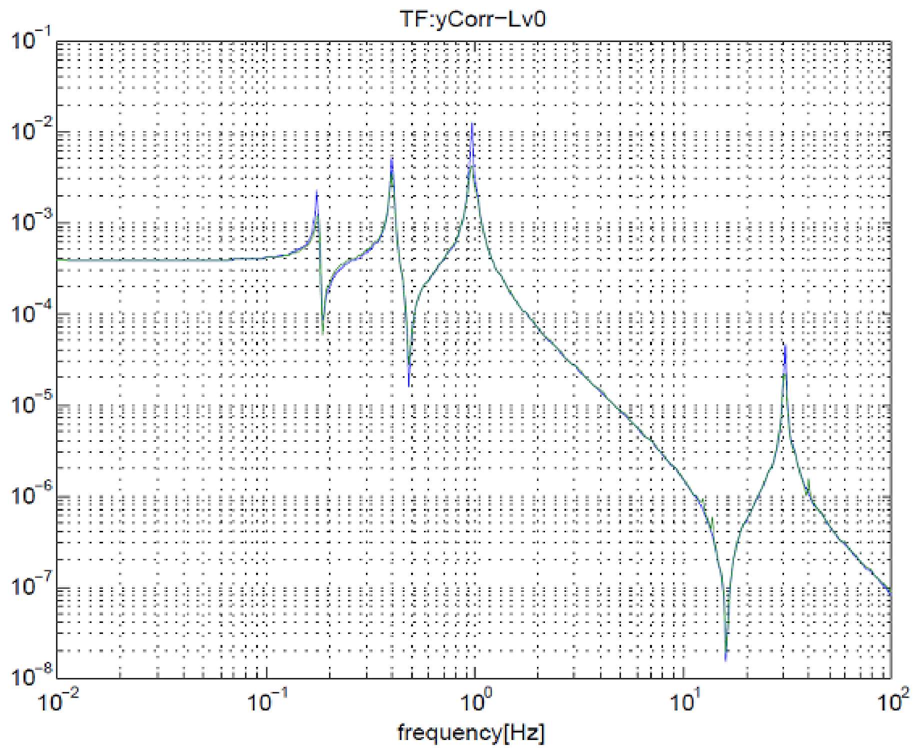
These simulations are useful to analize the performances of the selected controller,
in the same background conditions, when we replace the plant process mesaured with that
simulated .

We have produced the simulation related to the controller Cinit and Cfull

System with first resonance
at 180mHz

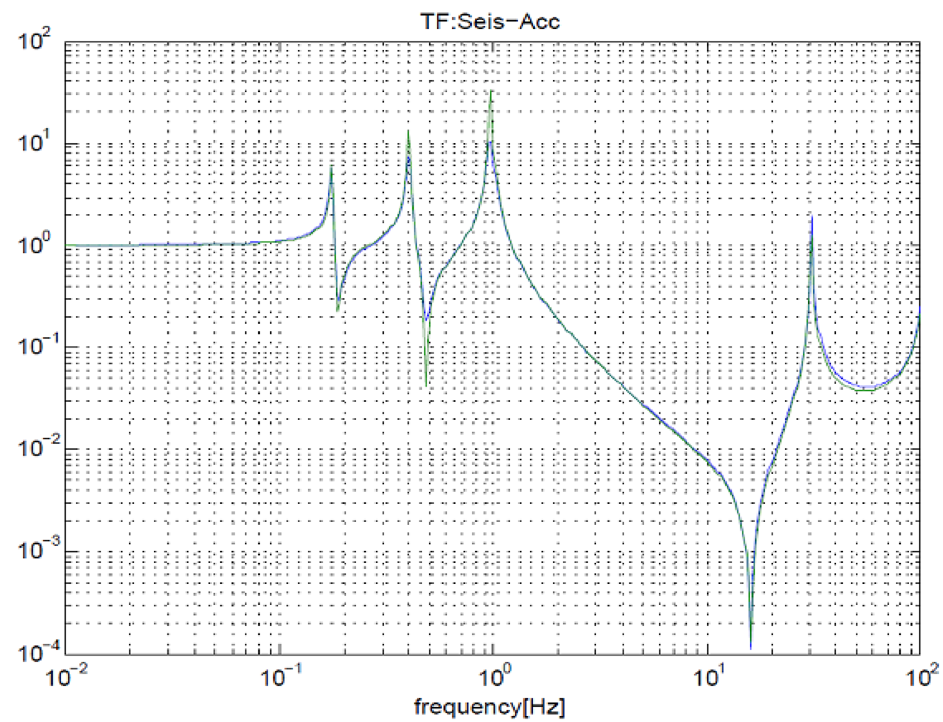
System with first resonace at 100
and at 80 mHz

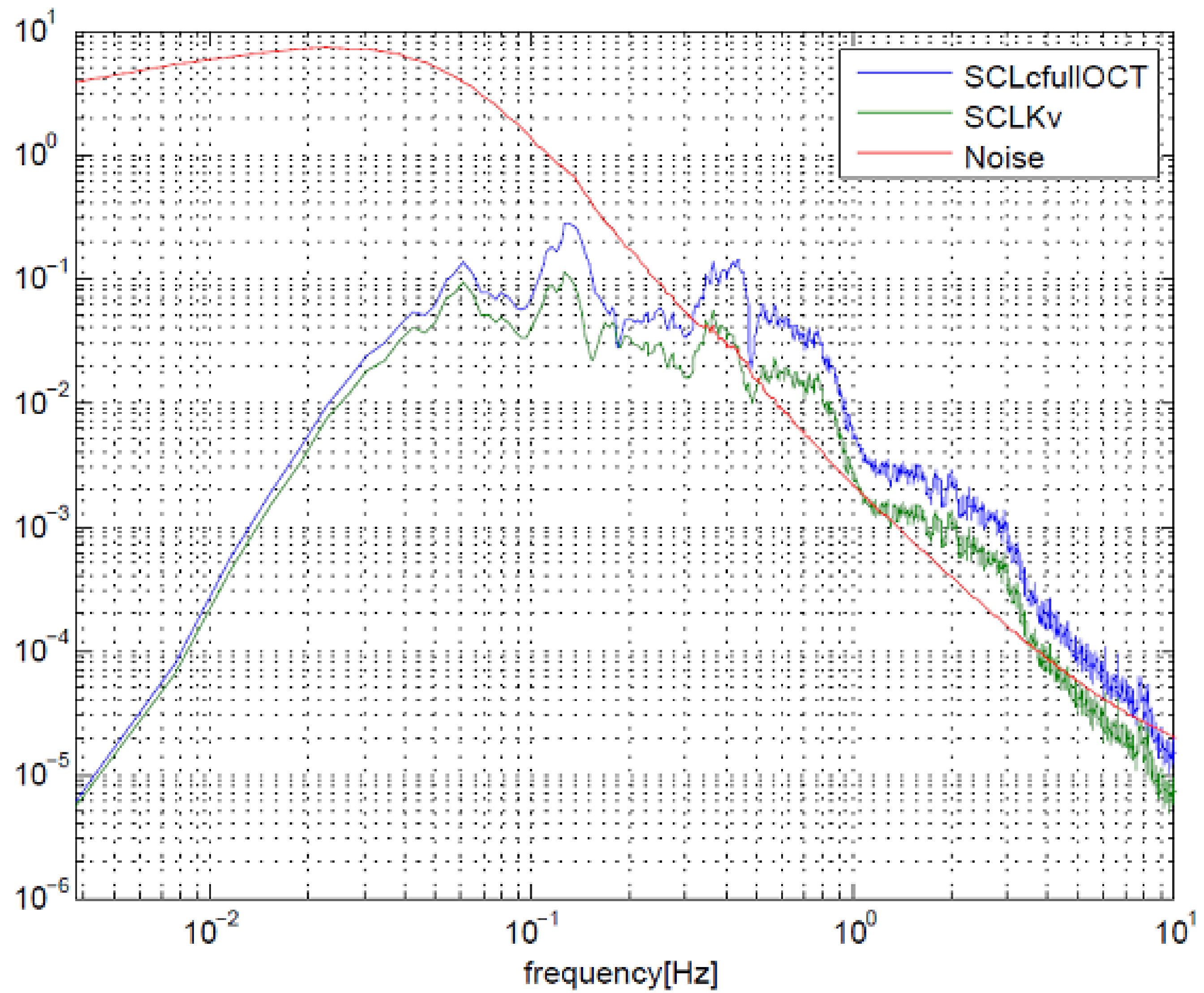
In these plots, the TFs simulated with OCTOPUS and the respective mesaured TFs are shown



This plot shows the TF related to Plant Process

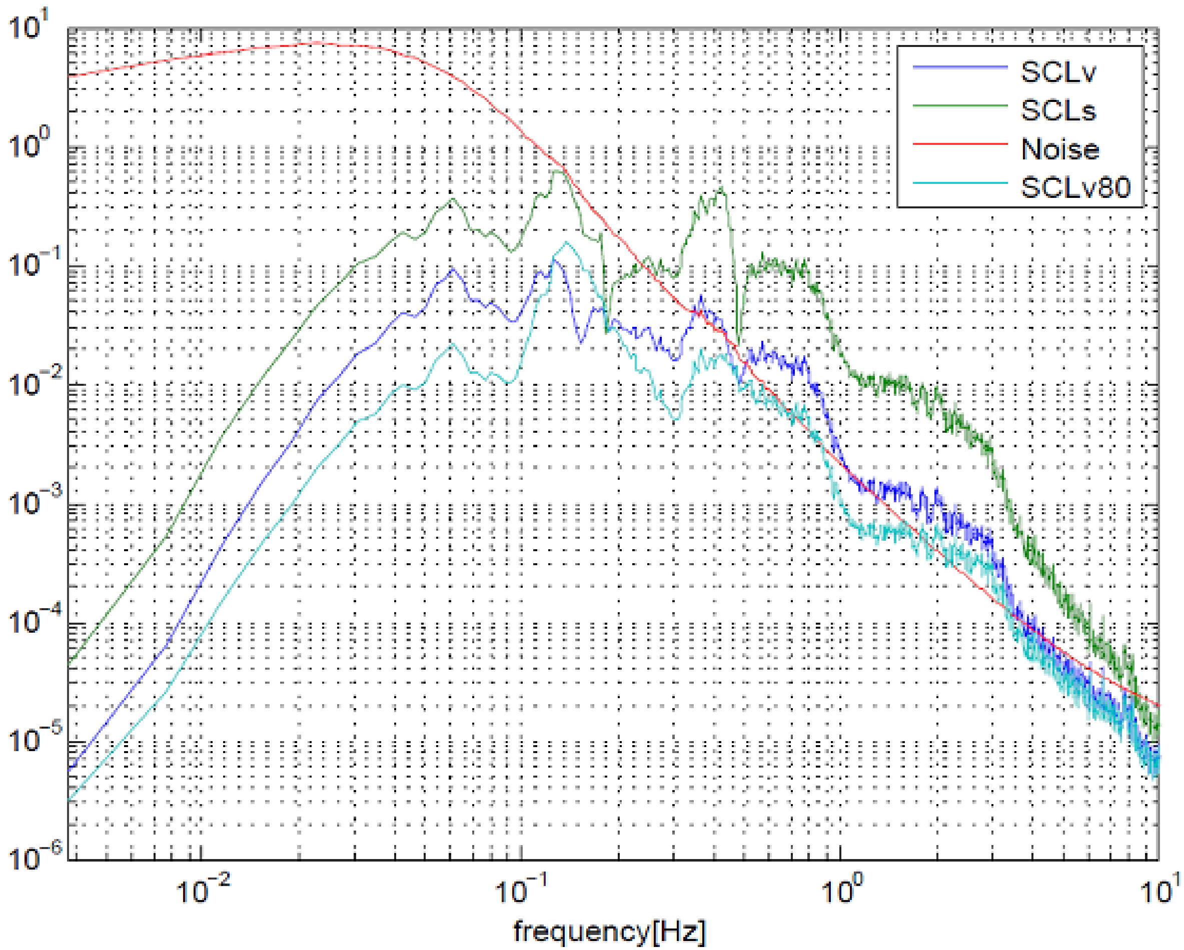
This plot shows the TF related to Seismic excitation.





In this plot, the comparison between the SCL with controller Cfull Applied to plant process that has first resonance at 180mHz (Sk) and the SCL with controller Cinit applied to plant process with first resonace at 100mHz are shown (Skv).

We can see that, in the same background conditions, the controller Cinit is more effective on the system Skv than the controller Cfull on system Sk.



The last plot shows the SCL,in the same background conditions, with controller Cinit applied at three different plant process :

1) First resonance at 180mHz (Sk)

2) First resonance at 100mHz (Skv)

3) First resonance at 80mHz (Skv80)

In the same background conditions, the controllerCinit has better performance on the different systems.

- Wich strategy should choose? The noise can be lowered?.......

Briefly :

- We have analize two strategies and the performance of the system with two controller.

- We can see as this different approach improve the performance of the control strategy.

- We conclude that better control strategy on tower MC is:

the strategy HP- LP 70 mHz   and the controller Cfull (gain 0.0100 at 1 Hz)

(OCTOPUS simulation)

- We have produce systems with high stiffness and low stiffness

- We conclude that lowering the vertical stiffness would allow an improvement even without
- increasing the gain of the controller